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Air Quality Maintenance Analysis in Phoenix, Arizona

AeroVironment, Inc.
Pasadena, CA

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This report presents results of an analysis for carbon monoxide and photochemical oxidants in the Phoenix Air Quality Maintenance Area. 11 Strategies were proposed for evaluation as to their effectiveness in attaining and maintaining the 8-hour CO and 1-hour oxidant standard. Three basic control strategies - traffic systems improvemants, including highway construction, improved mass transit, including transit incentives, and regional development planning - are part of the ongoing planning process and, therefore, were assumed through out the analysis, Two other control strategies - inspection/maintenance and carpooling - are already in operation but were evaluated in the same manner as the remaining six strategies. The six other strategies considered for inclusion in the Phoenix Air Quality Maintenance Plan were; periodic maintenance, vapor recovery, dealer emissions and driving schedule shifts.

In 1990 and 1995, the three basic control strategies alone would be sufficient to attain and maintain the standard because of decreasing emissions due to stricter controls on automobile emissions. However, the reduction would not be adequate to maintain the standard in the year 2000 and there would again be exceedances.

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SCOTTSDALE
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VAN BUREN STREET
BUCKEYE ROAD
APACHE BOULEVARD
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Research Triangle Park
North Carolina 27711

May 11, 1977

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Mr. Melvin Smith
Dr. Ivar Tombach
Mr. Manley Young

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Mr. Arthur Aymar	(Arizona Department of Health Services)
Mr. Mike Connors	(Maricopa Association of Governments)
Ms. Cathy Digges	(Arizona Department of Transportation)
Mr. James Dorre	(Arizona Department of Transportation)
Mr. Gary Jacobi	(Federal Highway Administration)
Mr. James Layden	(Maricopa County Department of Health Services)
Mr. Larry Yeager	(Arizona Department of Transportation)
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Traffic projections were supplied by the Transportation and Planning Office of the Maricopa Association of Governments. Current emissions and air quality data were provided by the Arizona Department of Health Services. Meteorological and additional air quality data were provided by the Maricopa County Health Department.

SUMMARY

This report presents results of an analysis for carbon monoxide and photochemical oxidants in the Phoenix Air Quality Maintenance Area.

An initial 53 control strategies were defined by the Phoenix Air Quality Maintenance Area Task Force (AQMATF) for study. Of these, 11 strategies were proposed for evaluation as to their effectiveness in attaining and maintaining the 8-hour CO and 1-hour oxidant standard. Three basic control strategies – traffic system improvements including highway construction, improved mass transit including transit incentives, and regional development planning – are part of the ongoing planning process and, therefore, were assumed throughout the analysis. Two other control strategies – inspection/maintenance and carpooling – are already in operation but were evaluated in the same manner as the remaining six strategies. The six other strategies considered for inclusion in the Phoenix Air Quality Maintenance Plan were: periodic maintenance, vapor recovery, dealer emissions control maintenance guarantee, clean air rebate, bicycle systems, and work and driving schedule shifts.

For CO, the evaluation was achieved by means of mathematical modeling using the APRAC-II model as well as by simple scaling. For oxidant, the EPA recommended approach, known as the Appendix J method, was used (Appendix J, Code of Federal Regulations, 40CFR51).

Predictions of severe-case CO readings were made for 1980, 1985, 1990, 1995 and 2000 and interpolated for years in between. The predictions showed that the CO 8-hour standard would not be attained until 1984 no matter what combinations of the eleven proposed strategies were implemented. For the 1985 case, the three basic control strategies (base case) with either periodic maintenance or periodic maintenance and carpooling would be the only combinations which would achieve attainment of the standard. In 1990 and 1995, the ~~base case~~ 3 basic control strategies alone would be sufficient to attain and maintain the standard because of decreasing emissions due to stricter controls on automobile emissions. However, the reduction would not be adequate to maintain the standard in the year 2000 and there would again be exceedances. The standard would be maintained in 1995 and 2000 with the addition of any of the following controls to the

base case: (a) inspection/maintenance, (b) periodic maintenance, (c) inspection/maintenance and carpooling, or (d) periodic maintenance and carpooling. Carpooling alone would not be sufficient to maintain the standard in 2000.

Oxidant air quality projections indicated that, with the three basic strategies, the oxidant standard would be attained in 1986 and maintained thereafter through 2000. The implementation of inspection/maintenance, periodic maintenance, carpooling, vapor recovery or their combinations would expedite the attainment and prolong the maintenance of the oxidant standard. The earliest year that the oxidant standard would be attained by any combination of strategies was predicted to be 1981.

Predicted effects from the four strategies of dealer emissions control maintenance guarantee, clean air rebate, bicycle systems, and work and driving schedule shifts were not discussed here because they did not provide any significant contribution to the maintenance of the CO or oxidant standards.

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I. INTRODUCTION

Under Section 51.12, paragraph (e), Part 40 of the Code of Federal Regulations (40CFR 51.12(e)), which was published on June 18, 1973, all states were required to identify areas which, due to the air quality at that time and/or projected growth rate, might have the potential for exceeding any national standards within the subsequent 10-year period. Analysis performed by the State of Arizona indicated that within the Phoenix Standard Metropolitan Statistical Area (SMSA) the 8-hour CO standard and the 1-hour oxidant standard were being exceeded. The Phoenix SMSA was therefore designated as an Air Quality Maintenance Area (AQMA) for carbon monoxide and photochemical oxidants. In May, 1976, an Air Quality Maintenance Area Task Force (AQMATF) was formed to develop an Air Quality Maintenance Plan to assure that emissions associated with projected growth and development would be compatible with the maintenance of the 8-hour CO and the 1-hour oxidant standards.

The primary objective of this study was to assess the effectiveness of emission control strategies proposed by the Phoenix AQMATF. 1975 was selected as the base year because that was the year with the latest available air quality and emissions information at the time this study was begun. Future years for which air quality and emissions were examined in detail were 1985 and 1995. For 1980, 1990 and 2000, air quality and emissions information was derived by interpolation or extrapolation.

In the assessment of the 8-hour CO air quality, the APRAC model developed by Stanford Research Institute and modified by AeroVironment, hereafter referred to as the APRAC-II model, was used. For oxidants, the approach recommended by the EPA, often referred to as the Appendix J method, was used (Appendix J, Code of Federal Regulations,40CFR 51).

II. DESCRIPTION OF THE STUDY AREA

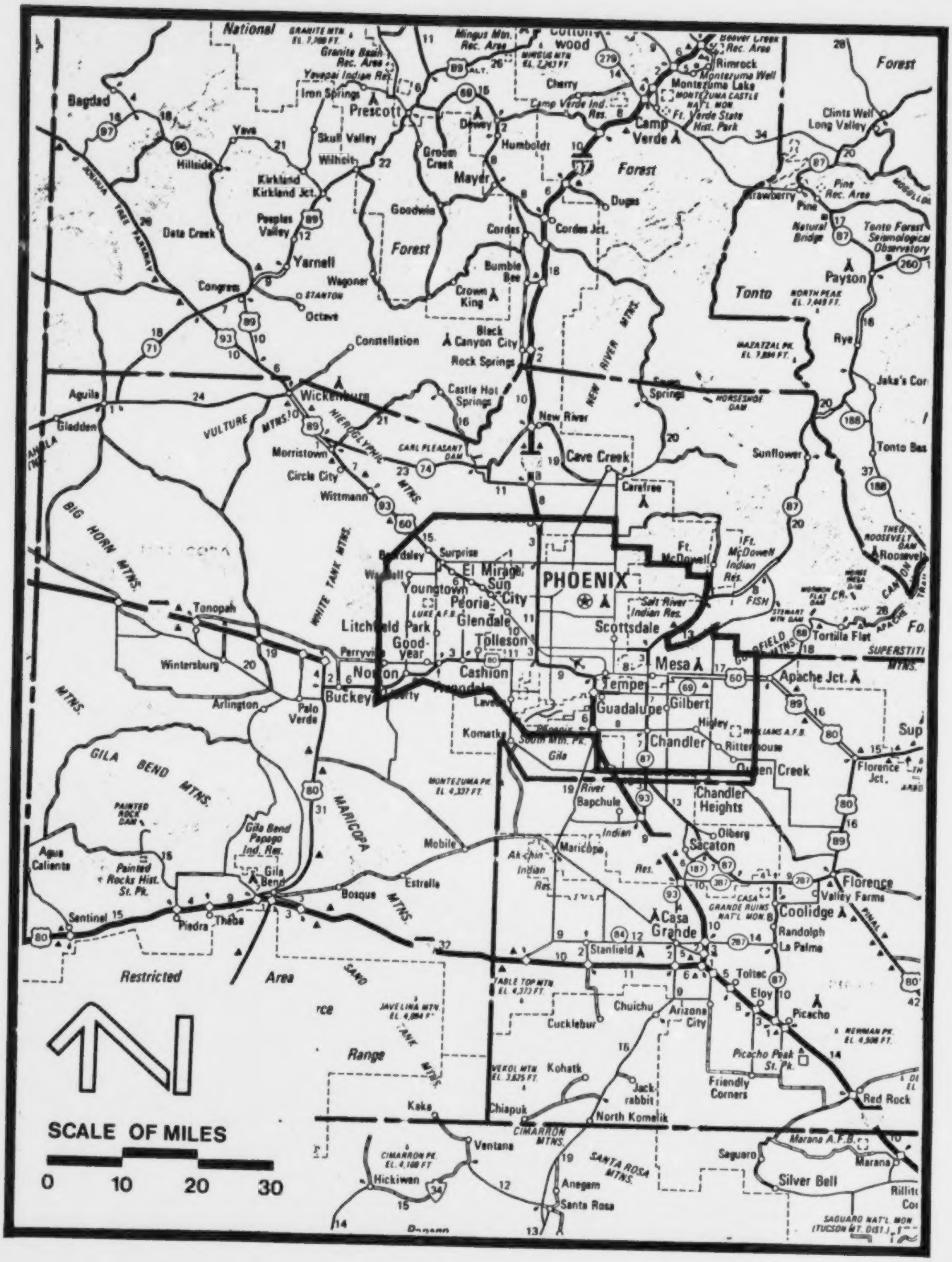
The study area is located near the center of the Salt River Valley, a broad, oval-shaped, nearly flat plain. The city of Phoenix is at the center of the area, with the cities of Glendale, Scottsdale, Mesa, Tempe, and other smaller communities surrounding it. The study area encompasses about 4400 square kilometers around Phoenix, which is at an elevation of about 335 m above mean sea level (MSL). It is located approximately 600 km east of Los Angeles, California and 600 km south-west of Albuquerque, New Mexico. (Figure 1).

The boundaries of the study area were defined by the AQMATF under the advice of the Maricopa Association of Governments (MAG), whose responsibilities include planning of regional developments and transportation in this area. Specifically, the study area is bounded to the north by Pinnacle Peak Road, to the south by Hunt Highway, to the east by Meridian Road, and to the west by Jackrabbit Trail (Figure 2).

The study area is protected on almost all sides by mountains. The Salt River Mountains are located about 10 km to the south of Phoenix and rise to 790 m MSL. The Phoenix Mountains lie 13 km to the north-northwest of Phoenix and have a maximum elevation of 700 m MSL. Twenty-nine kilometers to the southwest lie the Estrella Mountains, with a peak of 1006 m MSL, and 40 km to the west are found the White Tank Mountains with an elevation of 1220 m MSL. The Superstition Mountains are approximately 65 km to the east and rise to 1400 m MSL.

The Salt River runs from east to west through the valley but, owing to impounding dams upstream, it is usually dry. It is joined at the western boundary of the area by the Gila River from the south, and the Agua Fria River and New River from the north. It is also joined by the Verde River just beyond the study area from the northeast.

The population of the area in the base year, 1975, was around 1,230,000, of which over half was located in Phoenix. The area includes many attractions for tourists such as golf courses, swimming pools and over 500 annual special events from art shows to rodeos. Arizona State University is in Tempe, just east of Phoenix.


PHOENIX
Scottsdale
Mesa
Tempe
Guadalupe
Gilbert
Chandler
Glendale
Peoria
Sun City
El Mirage
Youngtown
Surprise
Litchfield Park
Goodyear
Tolleson
Cashion
Avondale
Buckeye
Palo Verde
Arlington
Tonopah
Wintersburg
Wickenburg
Morristown
Circle City
Wittmann
Aguila
Gladden
Congress
Yarnell
Peeples Valley
Kirkland
Kirkland Jct.
Skull Valley
Wilhoit
Prescott
Iron Springs
Bagdad
Hillside
Yava
Date Creek
Mayer
Humboldt
Dewey
Cordes
Cordes Jct.
Bumble Bee
Crown King
Black Canyon City
Rock Springs
Castle Hot Springs
New River
Cave Creek
Carefree
Camp Verde
Cottonwood
Cherry
Rimrock
Montezuma Lake
Payson
Pine
Strawberry
Rye
Clints Well
Long Valley
Sunflower
Roosevelt
Tortilla Flat
Apache Jct.
Queen Creek
Chandler Heights
Olberg
Sacaton
Florence
Florence Jct.
Valley Farms
Coolidge
Randolph
La Palma
Casa Grande
Stanfield
Maricopa
Mobile
Estrella
Bosque
Gila Bend
Theba
Piedra
Sentinel
Agua Caliente
Toltec
Eloy
Picacho
Arizona City
Chuichu
Cucklebur
Kohatk
Jackrabbit
Friendly Corners
North Komelik
Chiapuk
Kaka
Ventana
Hickiwan
Anegam
Santa Rosa
Red Rock
Marana
Silver Bell
Saguaro
Komatke
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SCALE OF MILES
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10
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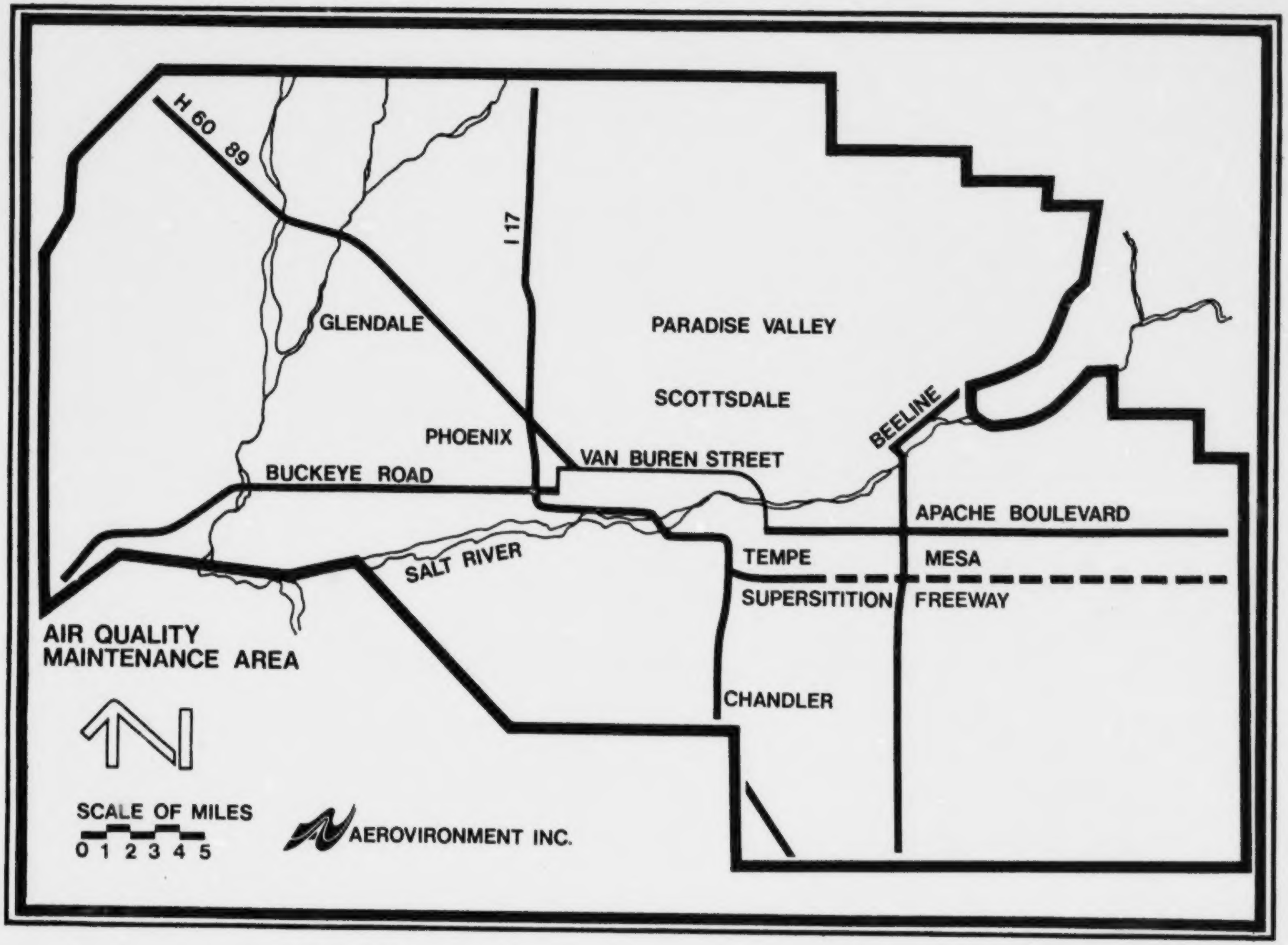
30

Figure 1. Location of study area.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BEELINE
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APACHE BOULEVARD
SALT RIVER
TEMPE
MESA
SUPERSITITION
FREEWAY
AIR QUALITY
MAINTENANCE AREA
CHANDLER
SCALE OF MILES
0 1 2 3 4 5
AEROVIRONMENT INC.

Figure 2. Phoenix study area boundaries.

III. BASE YEAR AIR QUALITY

Air quality measurements were made at eight sites in the Phoenix area in 1975, the locations of which are shown in Figure 3. Seven of these sites were operated by the Maricopa County Health Department (MCHD) and one by Arizona Department of Health Services (ADHS). Table 1 presents the name of each location, the operating agency, its address, and the components monitored.

Since this study is concerned with oxidants and carbon monoxide, only these two pollutants will be discussed.

PHOTOCHEMICAL OXIDANTS

Photochemical oxidant (ozone) was measured at six monitoring stations in Phoenix. At all of these stations, except location 3, ozone was measured by means of UV photometry. At location 3, colorimetric detection was used from January–August and UV photometry from September–December. All instruments were calibrated every six months using the EPA prescribed method of neutral buffered potassium iodide colorimetric analysis.

Exceedance of the one-hour National Ambient Air Quality standard for ozone (160 $\mu g/m^3$) was reported at five of the six sites monitoring this pollutant in 1975. Maximum one-hour concentrations and exceedances are presented in Table 2. Most frequent exceedances were reported at location 3, downtown, followed by locations 1 and 4, although location 4 monitored ozone only sporadically.

The highest and second highest one-hour ozone concentration averages reported during the field program were 298 $\mu g/m^3$ on 15 July 1975 at location 1 and 259 $\mu g/m^3$ on 30 June at location 3.

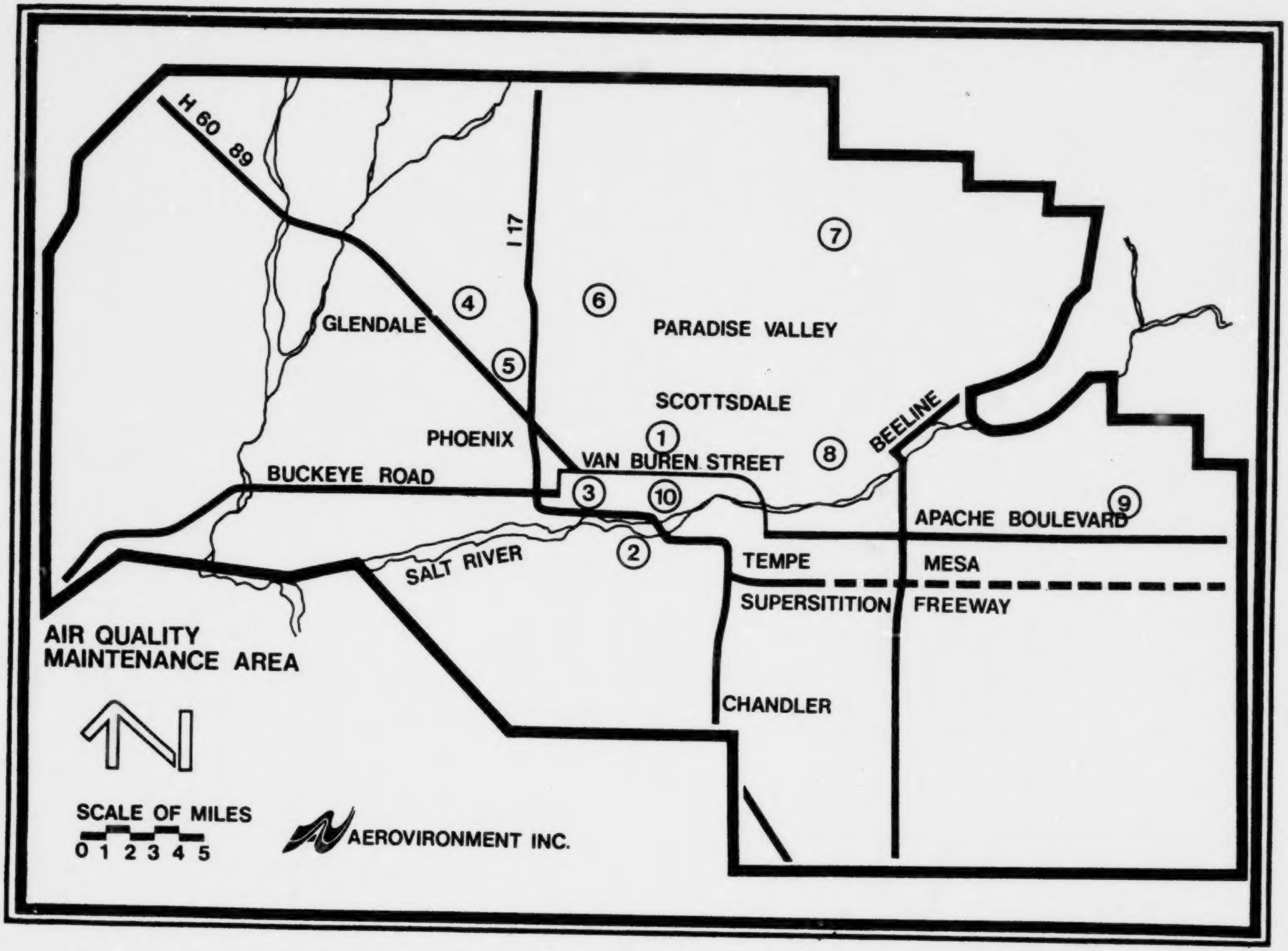
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Figure 3. Present meteorological and air quality stations in the Phoenix area. All stations were in operation in 1975 except for location 5. Locations 3 and 7 reported air quality data only. Location 10 reported meteorological data only.

Table 1. PHOENIX SITE LOCATIONS AND COMPONENTS MONITORED

Site	Name	Address	Operating Agency[1]	Components Monitored
1	Central Phoenix Station	1845 E. Roosevelt Phoenix	MCHD	CO, CH_4, THC, NO_2, SO_2, O_3, Part., WS, WD, and Solar Radiation
2	South Phoenix Station	4732 S. Central Ave. Phoenix	MCHD	CO, O_3, SO_2, Part., WS, WD
3	Arizona State Station	1740 W. Adams Phoenix	ADHS	CO, THC, NO_2, SO_2, O_3, Part., WS, WD
4	Glendale Station	6000 W. Olive Glendale	MCHD	CO, SO_2, O_3, Part. WS, WD
5	West Phoenix Station	3300 W. Camelback Phoenix	MCHD	No monitoring done in 1975
6	North Phoenix	8531 N. 6th Street Phoenix	MCHD	CO, O_3, WS, WD
7	North Scottsdale/ Paradise Valley Station	13665 N. Scottsdale Rd. Scottsdale	MCHD	Part. WS, WD
8	Scottsdale Station	2857 N. Miller Rd. Scottsdale	MCHD	CO, NO_2, O_3, Part. WS, WD, Solar Radiation
9	Mesa Station	3rd Place and Center Mesa	MCHD	CO, THC, SO_2, Part., WS, WD, T
10	Sky Harbor International Airport	Sky Harbor Blvd. Phoenix	NWS	Surface Weather Observations

[1] MCHD: Maricopa County Health Department
ADHS: Arizona Department of Health Services
NWS: National Weather Service

Table 2. MAXIMUM ONE-HOUR CONCENTRATIONS AND EXCEEDANCES OF THE FEDERAL ONE-HOUR STANDARD FOR OZONE (160 μg/m^3).

Location	Period Observed	Maximum 1 - Hour Concentration (μg/m^3)	Hours Std. was Exceeded	% Hrs. Std. was Exceeded	Days Std. was Exceeded	% Days Std. was Exceeded
1	Jan-Dec 75	298	25	0.4	12	4.7
2	Apr-Dec 75	135	0	0.0	0	0
3	Jan-Dec 75	259	53	0.7	25	7.5
4	Jan, Apr, May, July 1975	196	13	0.5	9	9.4
6	Jun-Dec 75	192	13	0.3	10	5.9
8	Jan-Dec 75	192	1	0.0	1	0.4

Figure 4 presents frequency distributions for continuous ozone measurements made during 1975 at locations 1 and 3. Readings at location 3 are generally higher except for the highest 0.04% of the observations. Median (50 percentile) values were 15 μg/m^3 at location 1 and 33 μg/m^3 at location 3.

Annual averages at the two sites were 24 μg/m^3 at location 1 and 39 μg/m^3 at location 3.

The highest monthly averages as well as the most frequent exceedances of the national standard occurred in summer. Eighty-one percent of the exceedances reported occurred during the period June through August. A July average of 70 μg/m^3 and an average daily one-hour maximum of 124 μg/m^3 was recorded at location 3. February, March, and April experienced no ozone exceedances and relatively low average values.

Table 3 presents a monthly and hourly breakdown of ozone national standard exceedances at location 1. Most frequent exceedances occurred during August and 72% of the exceedances occurred during the hours 1100-1500 MST at this location.

Figure 5 illustrates typical diurnal variation of ozone at location 1. Hourly averages for July are used for this figure. Other months show a similar variation, although the magnitude, especially of the peaks, is different. An increase in ozone levels from nighttime values is observed shortly after sunrise, building to a peak at noon when precursors (NMHC, oxides of nitrogen) have had time to react in the sunshine. The diurnal variation at location 3 is similar.

CARBON MONOXIDE

Carbon monoxide was measured at seven stations in Phoenix. At six of these stations, CO was measured by means of NDIR Spectroscopy. At location 3, CO was detected by flame ionization gas chromatography. The instrument spans were checked weekly with a dilute CO gas mixture, and EPA audited gas cylinders were used for multipoint calibrations.

No exceedances of the one-hour National Ambient Air Quality Standard for CO (40 mg/m^3) were reported at any of the monitoring sites. On the other hand,

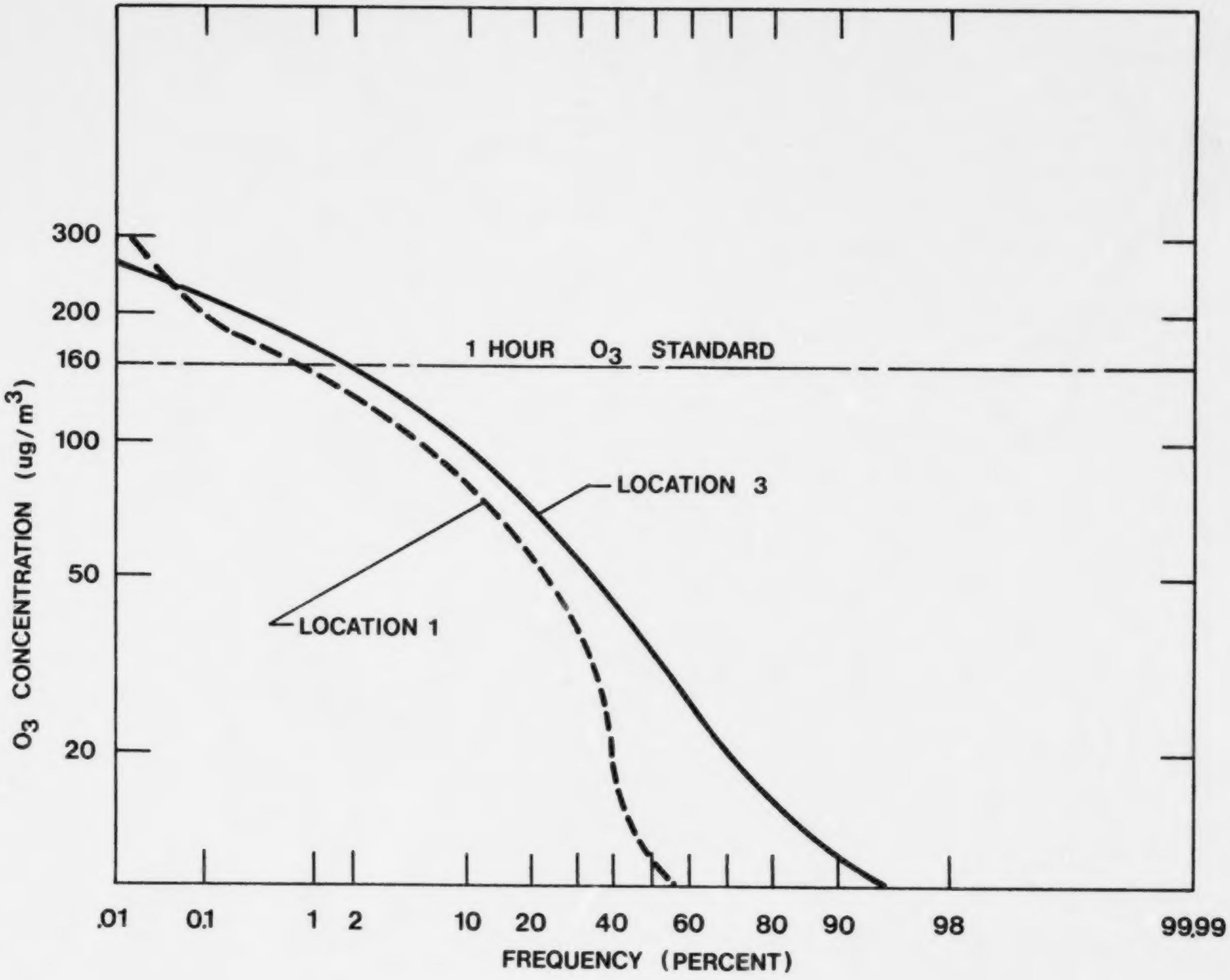


Figure 4. Cumulative frequency distribution for O_3 measurements made continuously during 1975 at Locations 1 and 3.

Table 3. NUMBER OF EXCEEDANCES OF 1-HOUR O_3 STANDARD BY MONTH AND HOUR OF DAY AT LOCATION 1.

Beg. Hr. Mo.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total By Month
Jan 75																									
Feb																									
Mar																									
Apr																									
May														1	1	1									3
Jun																1									1
Jul											1	1	2	2	1	1									8
Aug											2	1	4	2	2		1								12
Sept												1													1
Oct																									
Nov																									
Dec																									
Total By Hour											3	3	6	5	4	3	1								25

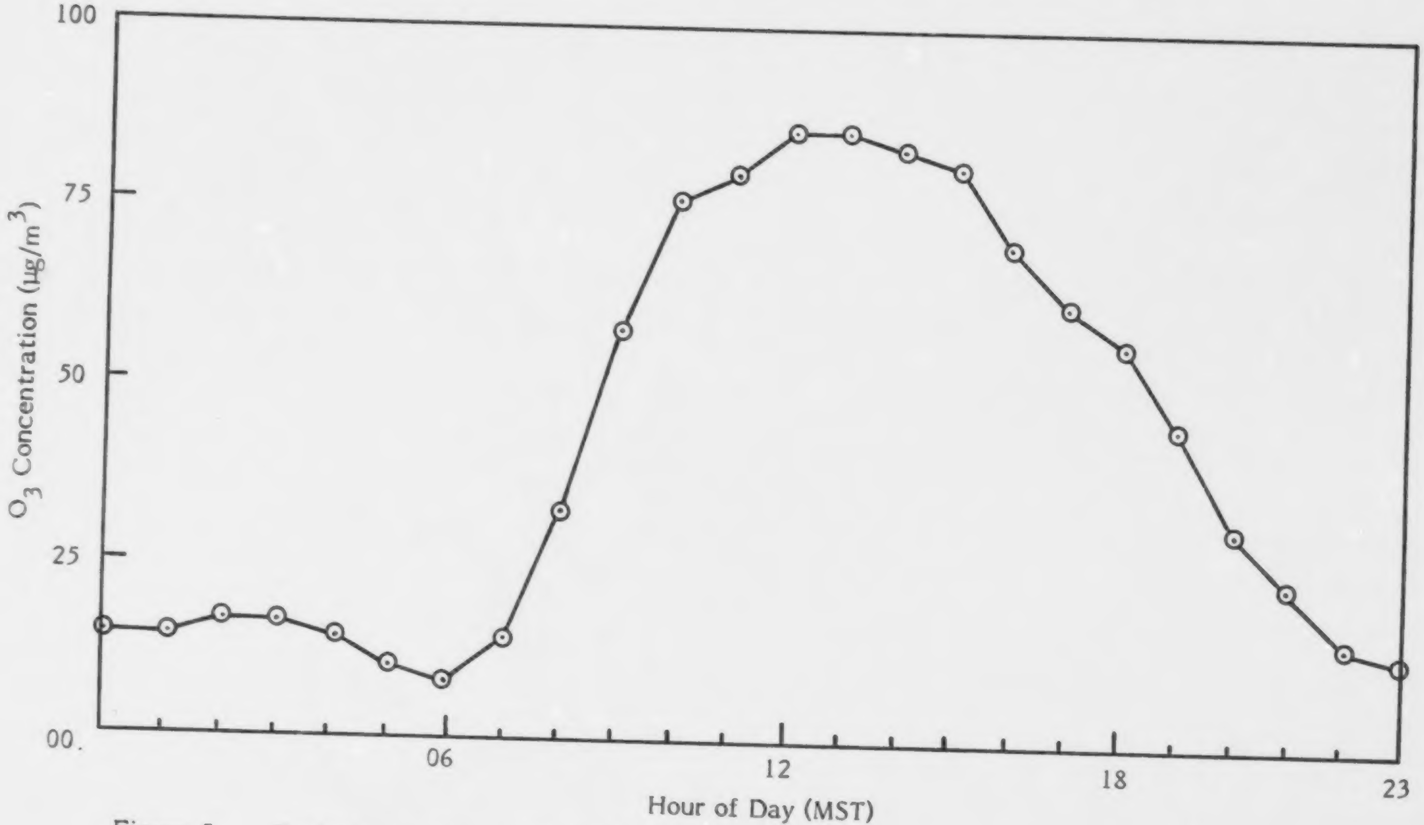


Figure 5. Typical diurnal variation of O_3 at location 1 in the summer. The ambient air quality standard is 160 $\mu g/m^3$ for one hour.

exceedances of the 8-hour standard (10 mg/m^3) were reported at all sites measuring CO, with a higher frequency (over 55 days in 1975) at locations 1 and 3 in downtown Phoenix. Frequency of exceedance statistics are presented in Table 4.

The highest and second highest one-hour averages were both 40 mg/m^3 reported twice at location 3 on 13 November 1975. The highest 8-hour average was 34 mg/m^3 on 13 November at location 3 and the second highest was 30 mg/m^3 on 4 November, again at location 3.

Figure 6 presents the frequency distribution for CO measurements made continuously during 1975 at location 1. The distribution at location 3 is very similar. The median value (50 percentile) at location 1 is approximately 2 mg/m^3.

Typical one-hour averages at all monitoring stations were below 3.5 mg/m^3. Lowest typical values were recorded at location 4 where the highest monthly average was only 3.4 mg/m^3. Highest typical values occurred at location 3 where monthly averages ranged from 1.3 to 6.7 mg/m^3.

The severe time of the year for CO in Phoenix is late fall and early winter. Average values during the period November through January at locations 1 and 3 were 6.1 and 6.2 mg/m^3 respectively, compared to 1.7 mg/m^3 during the period June through August. Seventy-three percent of the eight-hour national standard exceedances reported at location 1 occurred during the period November through January (Table 5) as did 78% of the exceedances at location 3. (It should be noted that little CO monitoring was done in July at location 3).

Figure 7 shows a typical diurnal variation of CO at location 1 during December 1975. Characteristic peaks occur in mid-morning and evening hours roughly corresponding to the peak morning traffic hours and limited mixing conditions prevalent in the evening. This pattern prevails throughout the year with only the magnitude of the peaks changing. Other locations exhibited the same pattern, although during the summer at some sites the trends were lost as the CO levels dropped to near background.

Table 4. PEAK 8-HOUR AVERAGES AND EXCEEDANCES OF THE FEDERAL 8-HOUR STANDARD FOR CO.

Location	Period Observed	Peak 8-Hrly. Avg. (mg/m^3)	No. of 8-hr Excds.	% Hrs.* 8-hr Std was Excd.	No.Days 8-hr Std was Excd.	% Days* 8-hr Std was Excd.
1	1/1/75-12/31/75	25.8	77	9.2	59	21.2
2	1/1/75-12/31/75	13.2	5	0.7	5	2.2
3	1/1/75-12/31/75	33.5	97	9.9	69	21.2
4	1/1/75-12/31/75	10.9	1	0.1	1	0.4
6	1/1/75-12/31/75	10.8	4	0.1	4	1.6
8	1/1/75-12/31/75	14.5	14	1.6	13	4.5
9	1/1/75-12/31/75	16.5	14	1.9	14	5.6

* The base for the calculation of percentages includes only 8-hour periods with at least five hourly observations.

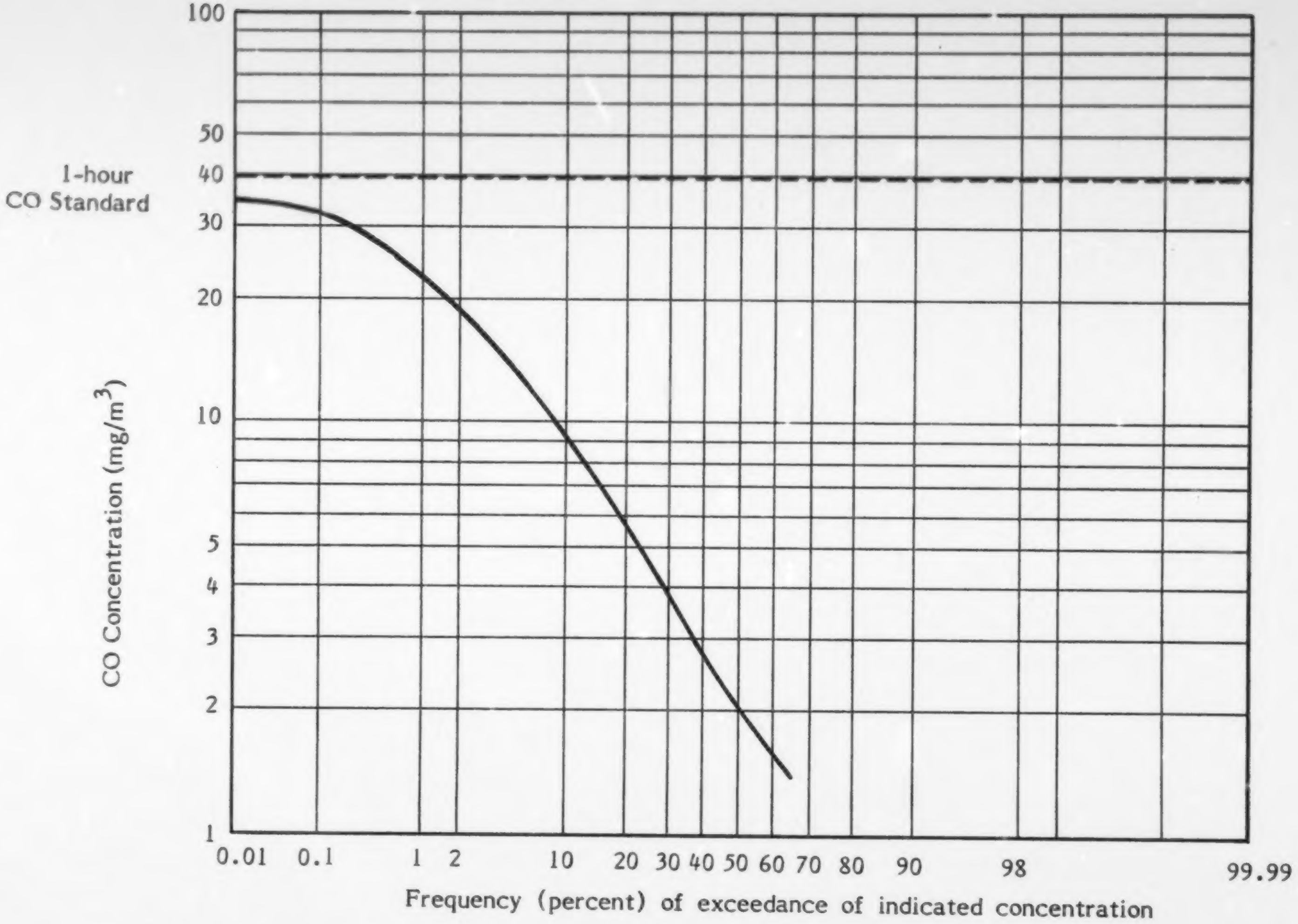


Figure 6. Cumulative frequency distribution for CO measurements made continuously during 1975 at location 1.

Table 5. NUMBER OF EXCEEDANCES OF 8-HOUR CO STANDARD BY MONTH AND HOUR ENDING AT LOCATION 1.

Beg. Hr. Mo.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total By Month
Jan 75		1	2		2	1															2	2	1	5	16
Feb	1	1																						2	4
Mar		1																							1
Apr	1																								1
May	1			1																					2
Jun			1																						1
Jul																									0
Aug																									0
Sept	1																							1	2
Oct	3	1	1																				3	2	10
Nov		2		1		1		1		1										1	2	3	3	3	18
Dec	6	1			1	1	1		2												1	3	3	3	22
Total By Hour	13	7	4	2	3	3	1	1	2	1										1	5	8	10	16	77

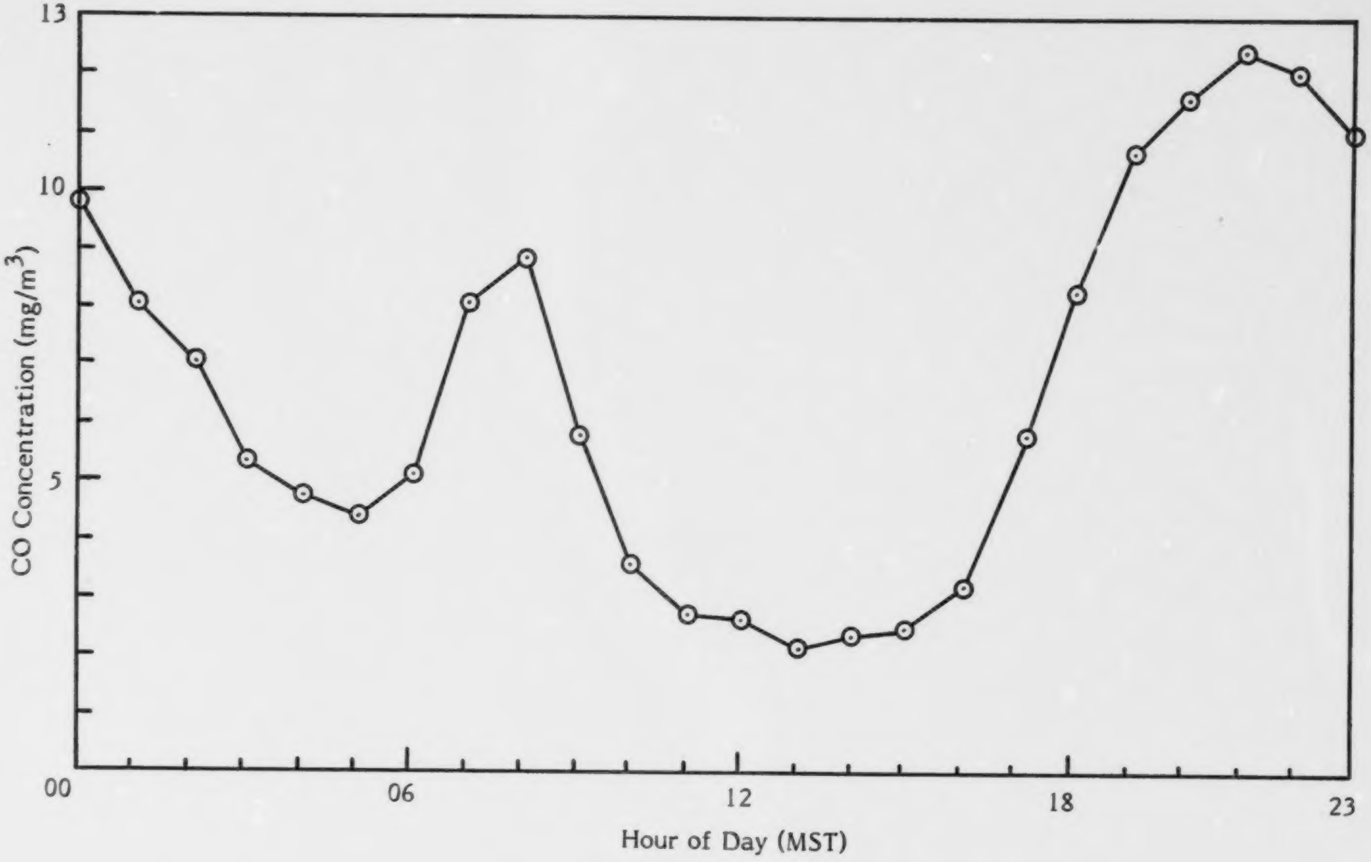


Figure 7. Typical diurnal variation of CO in downtown Phoenix in winter. The ambient air quality standards are 10 mg/m^3 for 8 hours and 40 mg/m^3 for 1 hour.

IV. BASE YEAR EMISSION INVENTORY

TRAFFIC SOURCES

Traffic emissions for the base year (1975) were derived from traffic link data in historical record format provided by Maricopa Association of Governments (MAG). The traffic link data was provided on a magnetic tape and was based on an existing Phoenix traffic network which incorporated a population of 1.23 million. The information which was extracted from the magnetic tape for use in computing the emissions included the x and y coordinates of the beginning and ending point of each link, the length of the link, the daily volume of vehicles on the link and the link's capacity.

In computing emissions on each link, a program developed by AeroVironment, called AVSUP5, was used. This program was a modified version of an EPA program, SUPP5 (U.S. EPA, 1976). Assumptions concerning diurnal traffic distribution, heavy-duty vehicle mix, vehicle speed, secondary traffic, hydrocarbon reactivity and details of emission computation in AVSUP5 are presented in Appendix A.

Table 6 presents VMT and motor vehicle emissions of CO and non-methane hydrocarbons (NMHC) by vehicle type. Light duty gasoline vehicles are obviously the major traffic source for both pollutants, contributing 65% of CO emissions and 61% of NMHC emissions on primary links. The fraction of light duty gasoline vehicles on the road varies from 66% to 78% depending on hour of day and facility type. Emissions from secondary traffic amount to 14% and 13% of total CO and NMHC traffic emissions respectively, slightly greater than its 12% share of the total VMT due to a lower vehicle speed.

NON-TRAFFIC SOURCES

Non-traffic emissions were obtained from Emission Inventory Report for the Phoenix Study Area (Pacific Environmental Services, 1976). Appendix C presents methodological and computational details. In general, PES used the 1972 National

Table 6. BASE YEAR (1975) VEHICLE MILES TRAVELED AND TRAFFIC EMISSIONS BY VEHICLE TYPE

Vehicle Type	VMT/Day x 10^6	Emissions CO (tons/day)	Emissions NMHC (tons/day)
Primary Traffic			
Light Duty Gasoline Autos	11.8	607.1	80.0
Light Duty Gasoline Trucks	2.9	182.3	30.6
Heavy Duty Gasoline Trucks	0.8	141.7	19.1
Light Duty Diesel Trucks	<0.1	<0.1	<0.1
Heavy Duty Diesel Trucks	0.2	4.0	0.7
Motorcycles	<0.1	3.3	0.9
Subtotal	15.8	938.3	131.4
Secondary Traffic	2.2	148.4	20.3
Total	18.0	1086.7	151.7

Emissions Data System (NEDS) Summary as a baseline document. This summary was updated to reflect 1975 emissions. Sources inventoried included gasoline handling, solvent evaporation, structural fires, industrial incineration, space heating, aircraft (commercial, civil, and military), railroads, and point sources (industrial and power plants).

Table 7 presents base year non-traffic emissions based on a population of 1.23 million. The major non-vehicular CO sources are airports, which account for 71% of total non-traffic emissions. The major NMHC source is that labeled "miscellaneous" and includes solvent evaporation, structural fires, and gasoline marketing. This category accounts for 71% of the non-traffic NMHC emissions.

Comparing non-traffic to traffic emissions, traffic constitutes 97% and 68% of total CO and NMHC emissions respectively.

Table 7. BASE YEAR (1975) NON-TRAFFIC EMISSIONS AND TOTAL EMISSION SUMMARY.

(tons/day)

Emission Source	Emissions	
	CO	MNHC
Point Sources	0.7	13.5
Area Sources		
Residential	0.6	--
Commercial/Institutional	1.1	0.3
Industrial	4.8	1.4
Miscellaneous		
Gas Handling	0.0	19.2
Solvent Evaporation	0.0	30.5
Structural Fires	1.0	0.0
Airports	27.1	2.9
Railroads	3.0	2.2
Total Non-Traffic	38.3	70.0
Total Traffic	1086.7	151.7
Grand Total	1125.0	221.7

V. PROPOSED EMISSION CONTROL STRATEGIES

Eleven emission control strategies were recommended by the AQMA Technical Operations Committee for evaluation by the AQMATF.

1) Traffic System Improvements Including Highway Construction

2) Improved Mass Transit Including Transit Incentives

3) Regional Development Planning

4) Inspection/Maintenance

5) Periodic Maintenance

6) Dealer Emissions Control Maintenance Guarantee

7) Clean Air Rebate

8) Carpooling

9) Vapor Recovery

10) Bicycle Systems

11) Work and Driving Schedule Shifts

Control strategies 4 and 8, namely the inspection/maintenance program and voluntary carpooling, are now in operation. Traffic system improvements, improved mass transit and regional development are ongoing activities and are implicit in the transportation system and land use plan presently adopted by the MAG Regional Council.

DESCRIPTION OF PROPOSED CONTROL STRATEGIES

A description of each control strategy is presented below:

Traffic System Improvements Including Highway Contruction

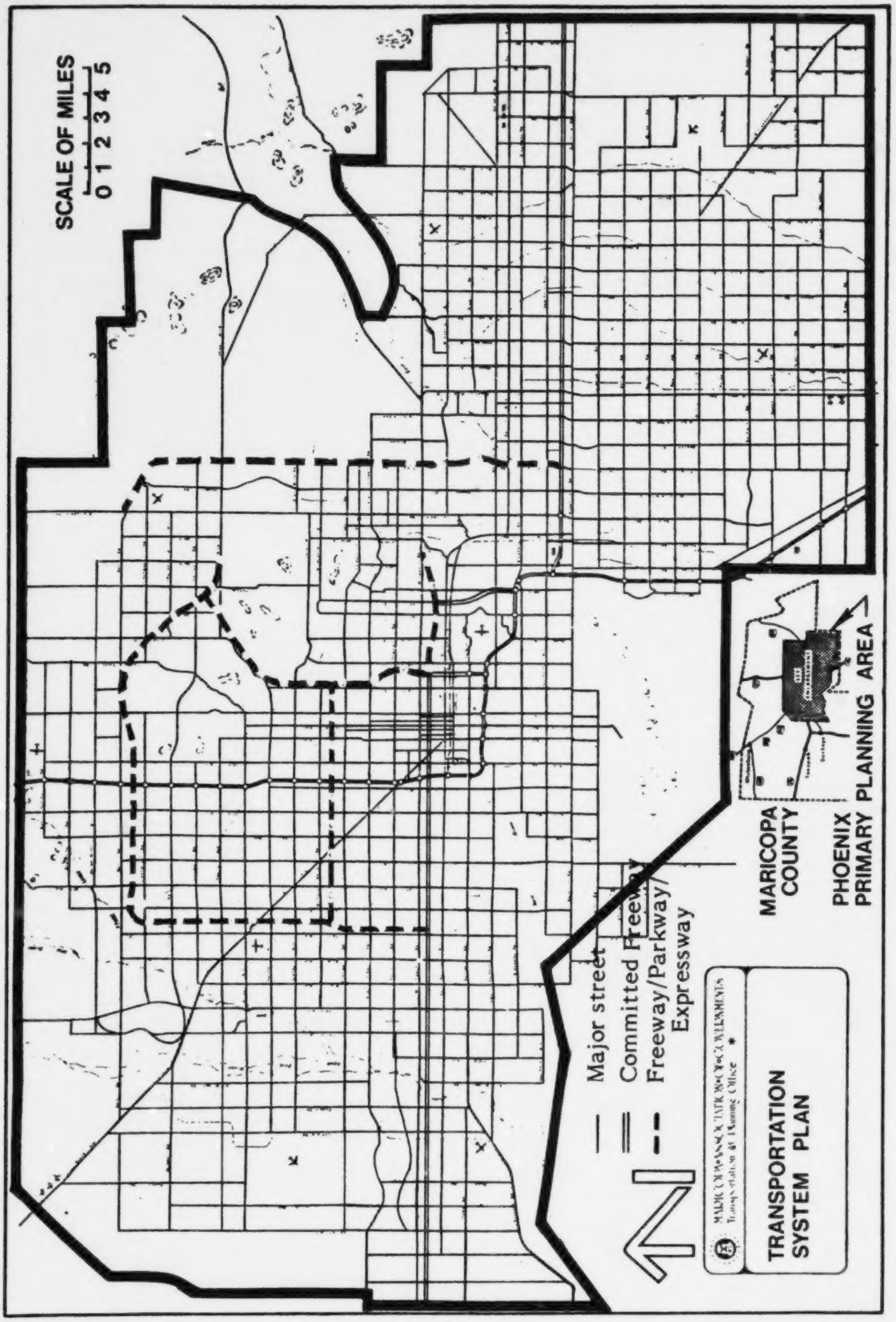
By upgrading the metropolitan area's traffic signal systems to operate under direct computer control, there would be an increase in the overall traffic speed, which would lead to a reduction in emissions of both CO and NMHC. Other improvements include freeway construction, major street construction, widening, freeway ramp metering, and the removal of on-street parking. It is the responsibility of the city, county and state governments, with the coordination provided by MAG, to implement these improvement measures.

Figure 8 presents the Transportation System Plan for Maricopa County that has been accepted by the Regional Council of the Maricopa Association of Governments as the basis for the continuing process of transportation system planning and implementation. Freeways in the present plan to be completed by 1985 are represented by double lines, while the remaining freeway system, depicted by dashed lines, is scheduled for completion in 1995. For comparison, the existing transportation network is presented in Figure 9. In 1975 there were 177 lane miles, by 1985 there will be 432 lane miles and in 1995, 825 lane miles. Under the current MAG plan, "freeway" includes parkways and expressways.

Improved Mass Transit Including Transit Incentives

The City of Phoenix operates the regional bus system in the Valley, which currently includes 182 buses in service with expansion to 400 buses scheduled by 1982. With this expansion, the service area and frequency of service will be increased and additional express bus service will be provided. Dial-a-ride service is already being provided in Glendale and there are plans being prepared in Scottsdale, Paradise Valley and Laveen for expansion of service to 90 square miles of the region.

Along with service expansion, incentives to ride transit are being provided. These include better passenger information systems such as ticket sales at many of the banks, and the construction of a bus terminal facility in downtown Phoenix. Other incentives,


SCALE OF MILES
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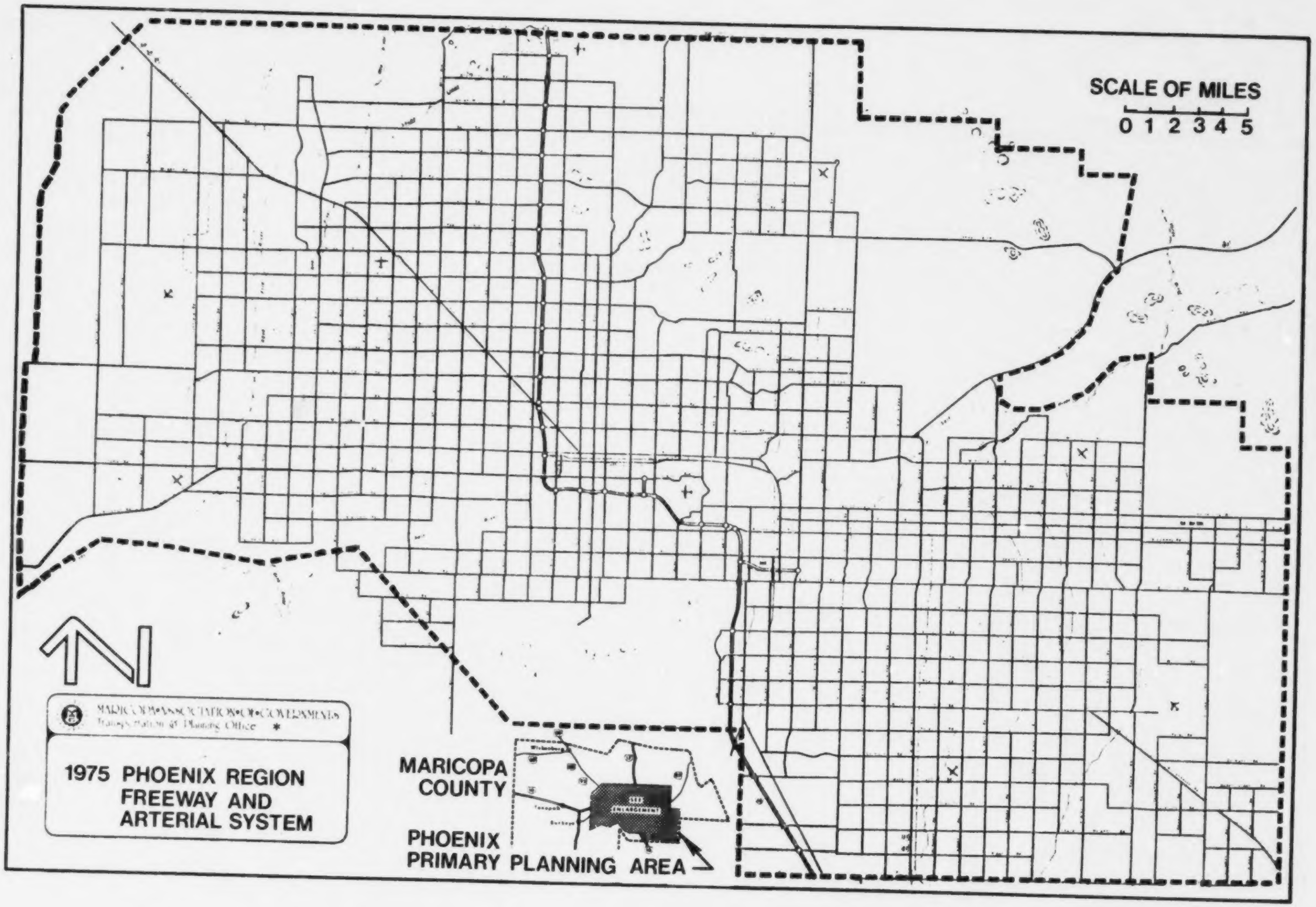
Major street
Committed Freeway
Freeway/Parkway/Expressway
MARICOPA ASSOCIATION OF GOVERNMENTS
Transportation & Planning Office
TRANSPORTATION SYSTEM PLAN
MARICOPA COUNTY
PHOENIX PRIMARY PLANNING AREA

Figure 8. Transportation system plan for Maricopa County.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Transportation & Planning Office
1975 PHOENIX REGION FREEWAY AND ARTERIAL SYSTEM
MARICOPA COUNTY
PHOENIX PRIMARY PLANNING AREA

Figure 9. Existing transportation network.

such as downtown shuttle services and reduced fares have been and will continue to be considered.

The MAG 1985 and 1995 traffic assignments used to develop the mobile source emissions inventories reflect increases in transit patronage from .6% in 1975 to 1.6% in 1985 and 1995, based on the MAG 1976-1981 Transit Development Program (1985) and long-range transit plan systems (1995). The bases for these transit projections are presented in Five Year Transit Development Program Fiscal Years 1977-1981, (MAG, 1976).

Regional Development Planning

The Maricopa Association of Governments (MAG) is responsible for conducting regional development planning in Maricopa County. The Composite Land Use Plan for Maricopa County (MAG, 1976) was used as the basis for the Air Quality Maintenance Analysis. This plan assumes a gradual increase in gross residential density from 3,500 persons per square mile in 1975 to 4,800 persons per square mile in 2000. This increase would occur as a result of infilling of vacant parcels and some redevelopment of older marginal or transitional neighborhoods. There would also be some increase in the percentage of medium density residential units (6–14 dwellings per acre) and a corresponding decrease in very low density units (less than 2 dwellings per acre). This concept also includes the Central Phoenix Plan which envisions substantial commercial development in the Central Avenue Corridor. Additional concentrations of commercial/service employment are located in the central core areas of Glendale, Mesa, Scottsdale and Tempe. Approximately 70 percent of all employment opportunities would be located in the "existing urban districts" (See Figure 10).

The general pattern of development is illustrated in Figure 11. Although much of the future development would occur in and immediately adjacent to the existing urban development, by 2000 the urbanized area would extend outward into new areas, most notably, northward to the CAP Canal, into the Northeast Scottsdale area, and along the I-10 Corridor – which would link Phoenix to the Tolleson, Goodyear, and Avondale areas. The outward spread of the urban area would be somewhat contained so that approximately 70 percent of existing agricultural lands would be preserved.

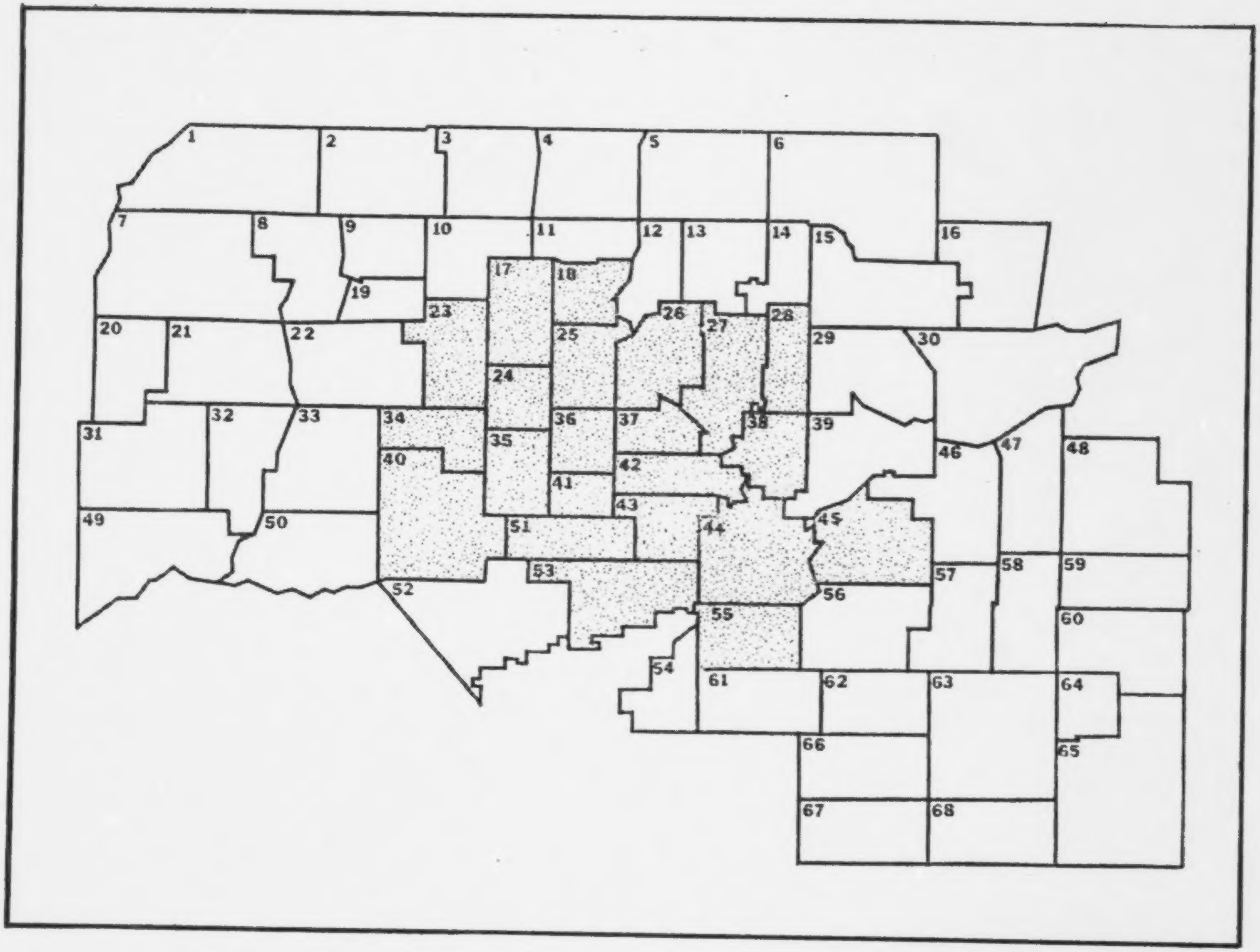
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Figure 10. Existing urban districts.

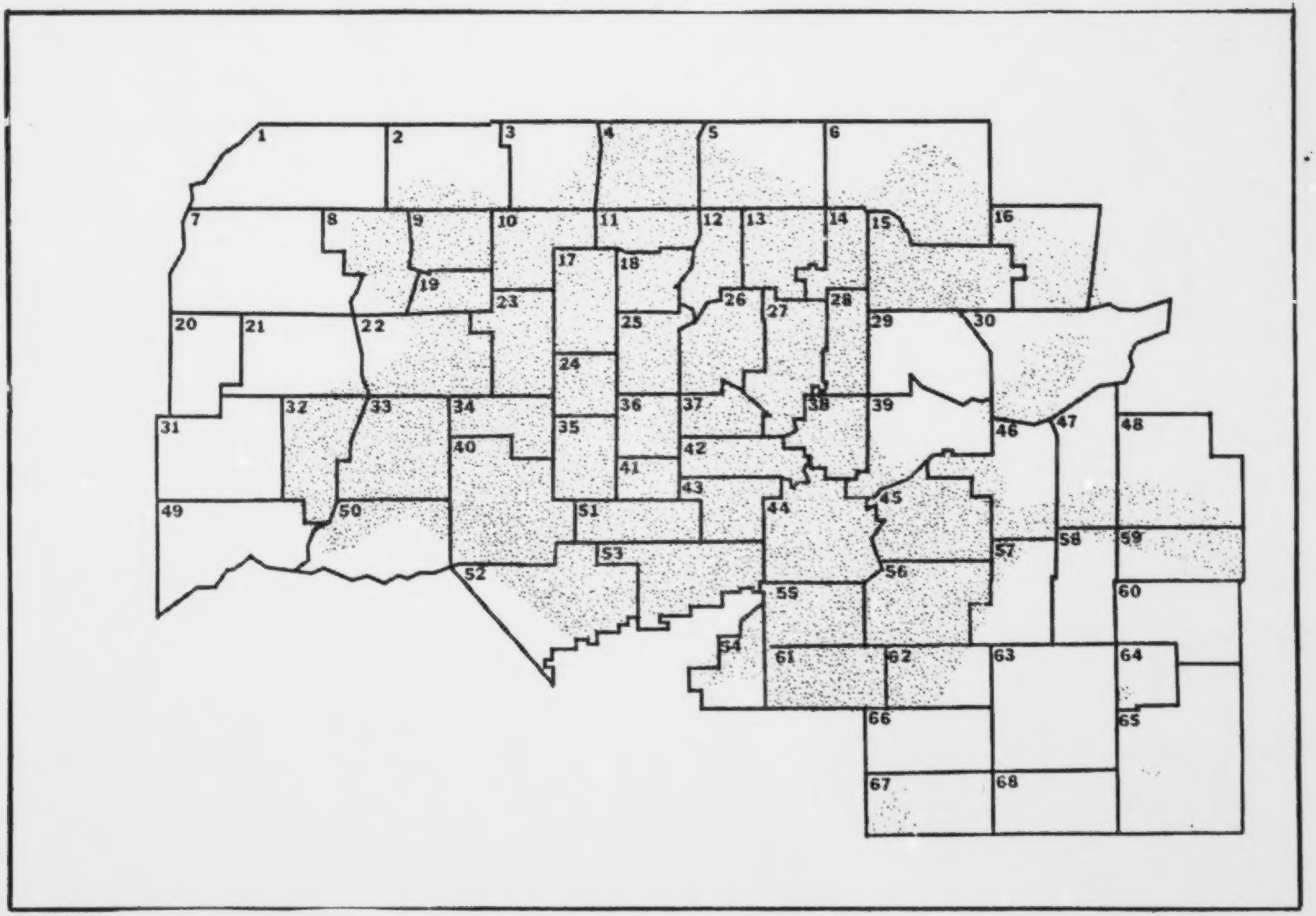
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Figure 11. Generalized urban boundaries projected to be developed by the year 2000.

Inspection/Maintenance

Under existing Arizona State Revised Statutes, beginning January 1, 1977 all vehicles under 14 years of age that are registered in Maricopa and Pima Counties for highway use are to be inspected at least once a year. For this purpose, a fleet of inspection stations including State operated ones would be available. The vehicles receiving the inspection are required to pass or be issued a waiver after performing the prescribed maintenance. This program is aimed at proper maintenance of the engine as a system, which would lead to a reduction of both CO and NMHC emissions.

Periodic Maintenance

This type of program is similar to the inspection/maintenance program except that instead of inspections, all vehicles undergo mandatory periodic maintenance, which results in maximum reductions since every car engine is adjusted or tuned. Periodic maintenance occurs at the same time as annual vehicle registration and relies upon the automotive repair industry to perform the necessary engine check and required maintenance. Repair facilities are required to be licensed and mechanics performing the maintenance must be certified.

Dealer Emissions Control Maintenance Guarantee

This control strategy requires a maintenance guarantee by the dealer to the vehicle buyer to perform all and necessary adjustments, maintenance and repair to meet required engine emission standards for a specified period of time, say five years. Cost of such a guarantee could probably be absorbed by the dealer and/or manufacturer or could be a direct cost to the purchaser.

Currently some automobile companies have programs related to this concept for new cars only. One warrantees its engine for 5 years or 75,000 miles, whichever comes first. Another warrantees its 4-cylinder aluminum engine for 5 years or 60,000 miles, whichever comes first. Both warrantees are honored only if the vehicle owner accomplishes the periodic maintenance specified.

Clean Air Rebate

This control strategy has two possible concepts. The first involves levying an emissions tax on all vehicles based on emissions performance. The second concept involves levying a tax based on the pollution contribution of a vehicle. This pollution contribution can be determined from the annual miles traveled by a particular vehicle and the emissions (in terms of grams per mile) from that vehicle. As an incentive to reducing emissions, there would be a rebate on cars that contribute less to air pollution than the average vehicle.

Carpooling

Increasing the number of riders per automobile can effect a major reduction in vehicles on the road. Average automobile occupancy in Phoenix is 1.35 persons per car. Average occupancy for work trips is presently 1.13 persons per car. Since most cars are capable of carrying four persons, there is considerable room for reducing automobile use and emissions through carpooling. Two things are essential to the success of a program to increase carpooling: convenience and necessity. The principal obstacle to carpooling is that carpools are highly restrictive in terms of the service offered. Carpoolers must have trip origins and destinations that are close to one another, must desire to travel at the same times of the day, and, to minimize the problems of locating carpool partners, must make trips that are repetitive from day to day. As a result, the greatest potential for increased carpool use is in connection with peak-period work trips, which are responsible for about 25% of urban area automobile emissions.

Vapor Recovery

Without proper vapor recovery devices, NMHC emissions result during the transfer of gasoline from one receptacle to another. In the process of filling a service station's main supply tanks, vapor that exists above the gasoline in the tanks can be vented back into the tanker, displacing the gasoline being transferred to the tanks. This means of preventing NMHC emissions to the atmosphere is known as Phase I Vapor Recovery. The control of vapor loss when filling the tank of a vehicle at a gasoline station is known as Phase II Vapor Recovery. This second phase can be accomplished by venting the vapor from the vehicle's tank, by a double hose, to the service station's main tanks.

Bicycle Systems

Increases in the use of bicycles in urban areas could diminish the total vehicle miles traveled by vehicles, which in turn would lead to a reduction in emissions.

There are approximately 50 miles of bikeways in operation in the Phoenix metropolitan area including striped lanes on existing streets and separate exclusive lanes. Bike lanes are required to be built adjacent to all new major streets in the City of Tempe. The City of Scottsdale has an adopted bicycle plan, while the City of Phoenix is in the process of developing policies associated with a city-wide network of bicycle paths. Short-term plans for the region presently provide for the addition of 90 miles of bikeways to the existing system.

Work and Driving Schedule Shifts

This control strategy would not result in any reduction in vehicle miles traveled. However, by staggering the starting and quitting hours, work-related trips would be distributed over a longer time period thereby alleviating peak-hour congestion and leading to lesser CO and NMHC emissions. The spreading of emissions over a longer period also has the effect of decreasing peak hour CO levels.

EFFECTIVENESS OF PROPOSED CONTROL STRATEGIES – DETERMINED BY THE TECHNICAL OPERATIONS COMMITTEE

The effectiveness of these control strategies in reducing CO and NMHC emissions was determined by the AQMA Technical Operations Committee. This effectiveness data was then used for calculating emissions projections as discussed in the next chapter.

Implicit in the traffic data base from which emission projections were developed was the existence of the first three control strategies, viz., traffic system improvements, improved mass transit and regional development planning. No specific emission reductions were assigned to these strategies.

According to the latest results obtained by the Bureau of Vehicular Emissions, the inspection/ maintenance program would lead to 22% and 37% reduction in CO and NMHC emissions, respectively, from all light duty vehicles, including motorcycles. This reduction corresponded to a 16.8% failure rate as observed during the first three months of the Phoenix I/M program. Such a program would also result in 11% and 7% reduction in CO and NMHC emissions, respectively, from all heavy duty vehicles. Percentage emission reductions for heavy duty vehicles were obtained from the Transportation Control Strategies (ASDH, 1973). These reductions could be increased by adjusting emission standards.

Periodic maintenance would have the effect of reducing CO and NMHC emissions from all light and heavy duty vehicles by 35% and 34% respectively. This data was derived from a study performed by Clean Air Research Company for the California Air Resources Board. (Gockel, 1973).

Both the dealer emissions guarantee and clean air rebate are incentive programs designed to support the inspection/maintenance or periodic maintenance programs and would, by themselves, be ineffective in reducing vehicle emissions.

Carpooling programs aimed at reducing work trips could reasonably be expected to increase car occupancy from 1.35 in 1976 to 1.4 in 1985 and 1.5 in 1995. This would lead to a decrease of 5% in both CO and NMHC emissions from all light duty vehicles in 1985 and a decrease of 12% and 11% for CO and NMHC respectively, in 1995. These figures are based on results of the MAG Sketch Planning Models.

It is anticipated that if vapor recovery were implemented, Phase I would be in full operation by 1985 and both Phase I and II would be in effect by 1995. These dates are fairly conservative as the technology for vapor recovery has already been developed and actual implementation could be achieved more rapidly if necessary. There would be a 36% reduction in NMHC emissions from gasoline marketing sources in Phoenix in 1985 from Phase I and an 81% reduction in NMHC emissions in 1995 with both Phase I and II in operation. (Witherspoon, 1976).

Bicycle systems are not expected to have any effect on emissions by 1985 but would reduce both CO and NMHC emissions in 1995 by 0.6%. This effectiveness data is inferred from the San Diego Air Quality Planning Report (Planning Environment International, 1976).

The implementation of work and driving shifts would flatten out the traffic during the morning and afternoon rush hours. Effects of this control strategy are presented in Table 8.

Table 8. CHANGES IN PERCENT AVERAGE DAILY TRAFFIC (% ADT) WITH THE IMPLEMENTATION OF WORK AND DRIVING SHIFTS.

Hour of Day Affected	Freeway % ADT		Arterial % ADT	
	Base Case	Working and Driving Shifts	Base Case	Working and Driving Shifts
6	4.5	7.2	3.1	5.9
7	9.4	7.2	8.1	5.9
8	7.7	7.2	6.5	5.9
15	7.1	8.4	7.5	8.2
16	9.4	8.3	8.8	8.2
17	8.5	8.3	8.2	8.1

VI. EMISSIONS INVENTORY PROJECTION

PROJECTION METHODOLOGY

Emission projections were made for 1980, 1985, 1990, 1995, and 2000. The effects of selected CO and NMHC emission control strategies on areawide emissions were also determined. These emission projections were based on a population forecast for 1995 of 2.2 million (1.7 million in 1985), which is the mean value of the latest Arizona Department of Economic Security's low and high projections for Maricopa County (DES, 1976), adjusted for the smaller study area.

Vehicle miles traveled (VMT) for 1985 and 1995 were obtained from traffic link data provided by MAG. The 1985 traffic data was derived from the Approved Regional Transportation Plan (MAG, 1976) including existing and committed freeways for 1985 and based on a 1.7 million population. The 1995 traffic network was also derived from the regional plan assuming a 2.2 million population and a planned freeway configuration for 1995. Both traffic systems include changes which would be incorporated with the implementation of traffic system improvements, improved mass transit, and regional development training by the given study year. VMT for 1980, 1990, and 2000 were derived using linear interpolation or extrapolation for each vehicle class. The VMT data are presented in Figure 12. Freeway lane miles are 177 for 1975, 432 for 1985 and 825 for 1995. Emissions were then derived from these years using emission factors appropriate to those years, VMT as described above, and an average speed for each vehicle class and roadway type. This average speed was based on linear interpolation or extrapolation of speeds in 1975, 1985, and 1995.

Non-traffic emissions for 1995 were obtained using projections in Emission Inventory Report for the Phoenix Study Area, (PES, 1976) for a population of 1.9 million. These were revised to reflect a 2.2 million population level by taking into account changes in growth rate due to this higher population estimate. Projections for 1980, 1985, 1990, and 2000 were made by assigning appropriate growth rates and emission factor adjustments to each source and applying these to the base year inventory. Growth rates were generally derived through linear interpolation or extrapolation based on 1975 and 1995 land use areas, population, etc. Emission factor adjustments were based on forecast schedules of emission control measures (e.g., pilot light phaseout and energy conservation).

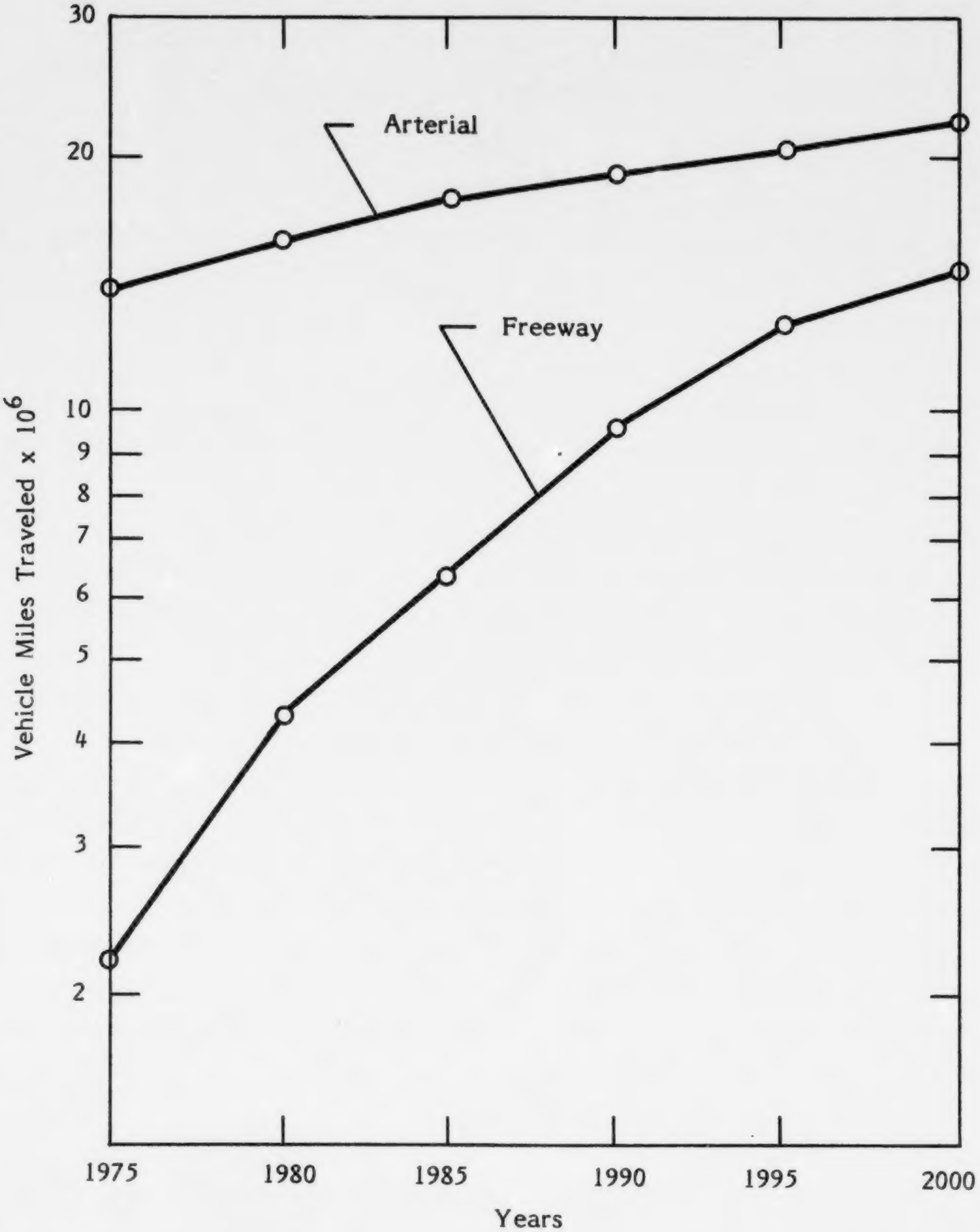


Figure 12. Projected vehicle miles traveled per day by facility type.

Details of emission projections are presented in Appendices B and D.

PROJECTED EMISSIONS

Projected traffic emissions are presented in Table 9. Because traffic system improvement, improved mass transit, and regional development planning were implicit in the traffic network data provided by MAG, a scenario without these controls was not analyzed. Since these three control strategies constitute the basic scenario, projections incorporating them will be referred to as the "base case."

The general base case trend is illustrated by Figure 13. Comparison with Figure 12 presented earlier reveals that, while VMT increases, traffic emissions decrease through 1990 due primarily to increasingly strict emission control regulations on light duty gasoline powered vehicles. This vehicle class continues to be the primary NMHC contributor, but by 1995 the major contribution to primary traffic CO emissions has become heavy duty gasoline trucks, since projected emission control regulations on this vehicle class are not as strict as on light-duty vehicles. The contribution of heavy duty gasoline trucks is expected to increase to 54% of primary traffic CO emissions by 1995.

Table 10 presents projected non-traffic emissions. The trend is illustrated graphically in Figure 14. CO emissions are expected to increase, primarily due to increased airport activity. Airports will continue to be the dominant non-traffic source, contributing 65% in 1995. NMHC emissions are expected to decrease through 1995 in spite of increased gasoline marketing primarily because of the increased use of non-polluting solvents. Miscellaneous emissions, primarily solvent evaporation and gasoline marketing, will continue to be the dominant non-traffic NMHC source in 1995, contributing 63%.

Despite major emission reductions, traffic will continue to be the major contributor to the total CO emission picture, accounting for 85% in 1995. Traffic emissions will only be 46% of the total NMHC emissions in 1995, however.

Without implementation of any of the control strategies except the first three, described in Chapter V, total emissions will have been reduced by 67% and 47% for CO and NMHC respectively by 1995. The total emission trend for both pollutants is illustrated in Figure 15.

Table 9. PROJECTED TRAFFIC EMISSIONS – BASE CASE.*
(tons/day)

	1980		1985		1990		1995		2000	
Vehicle Type	CO	NMHC	CO	NMHC	CO	NMHC	CO	NMHC	CO	NMHC
Primary Traffic										
Light Duty Autos	293.6	59.4	116.3	32.8	59.8	21.1	65.4	21.9	74.4	24.6
Light Duty Trucks	109.1	22.0	67.1	15.1	50.3	11.7	57.2	11.1	65.6	12.7
Heavy Duty Gas Trucks	132.1	15.2	123.7	11.4	135.2	10.4	155.4	12.7	177.9	14.5
Light Duty Diesel Trucks	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Heavy Duty Diesel Trucks	4.6	0.9	5.3	1.1	6.2	1.2	7.2	1.5	8.1	1.7
Motorcycles	4.0	0.9	4.2	0.9	1.4	0.4	1.6	0.5	1.8	0.5
Subtotal	543.4	98.4	316.6	61.2	252.9	44.8	286.9	47.7	327.8	54.0
Secondary Traffic	91.7	14.9	47.6	9.2	29.6	6.0	31.7	6.5	38.9	7.0
Total Traffic	635.1	114.3	364.2	70.4	282.5	50.8	318.6	54.1	366.7	61.0

* Actually incorporates the following controls: (1) traffic system improvements, (2) improved mass transit, and (3) regional development planning.

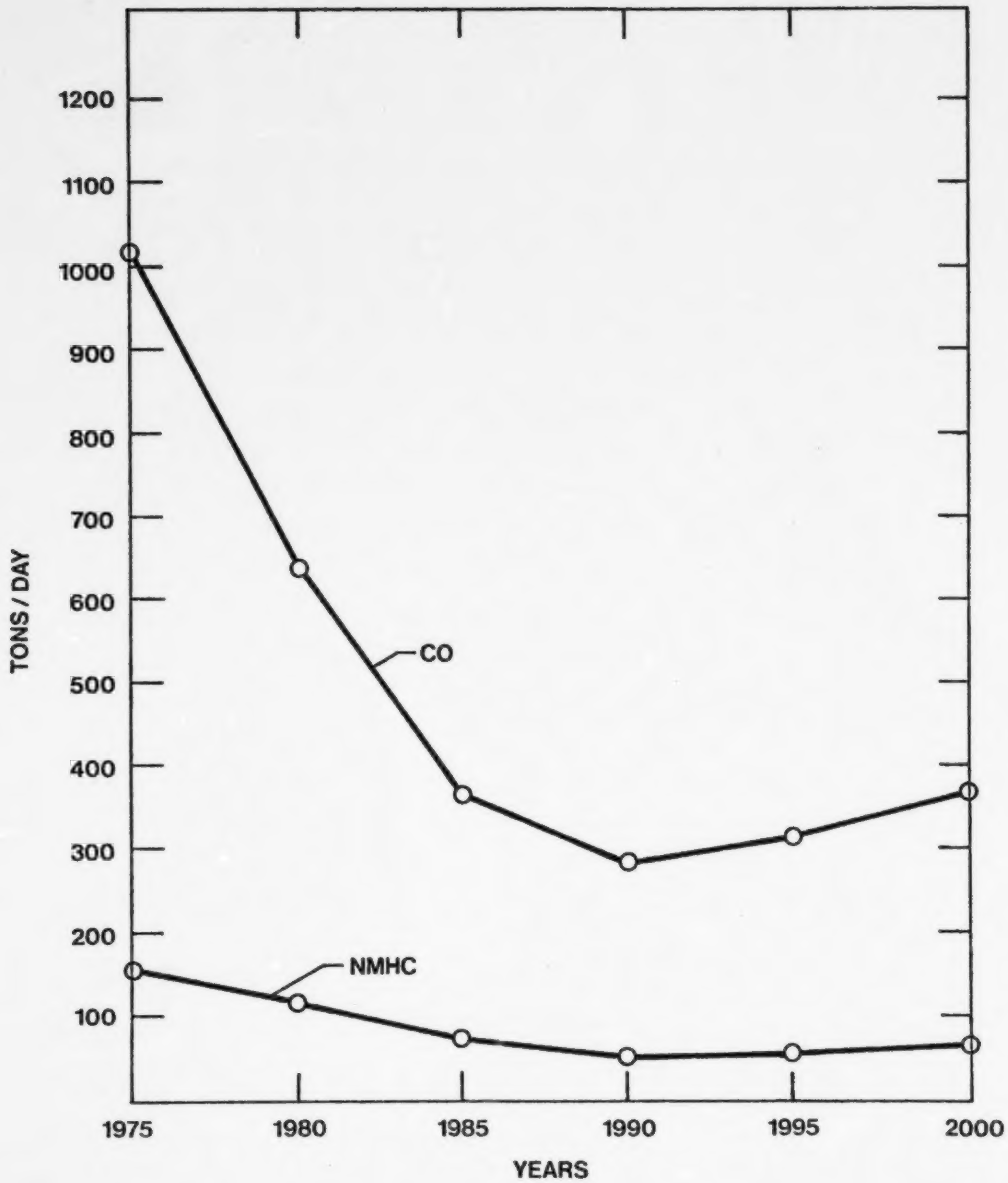


Figure 13. Traffic emissions trend through 2000.

Table 10. PROJECTED NON-TRAFFIC EMISSIONS – BASE CASE.

(tons/day)

Emission Source	1980		1985		1990		1995		2000	
	CO	NMHC	CO	NMHC	CO	NMHC	CO	NMHC	CO	NMHC
Point Sources	0.7	13.5	0.7	13.5	0.6	13.5	0.6	13.4	0.6	13.4
Area Sources										
Residential	0.8	--	0.9	--	1.0	--	1.1	--	1.2	--
Commercial/Institutional	1.3	0.3	1.5	0.4	1.6	0.4	1.7	0.4	1.9	0.5
Industrial	5.8	1.7	5.8	1.7	7.8	2.3	10.1	2.9	13.5	3.9
Miscellaneous										
Gas Handling	0.0	22.8	0.0	26.5	0.0	30.4	0.0	34.3	0.0	38.2
Solvent Evaporation	0.0	27.3	0.0	21.1	0.0	14.5	0.0	5.5	0.0	6.1
Structural Fires	1.2	0.0	1.4	0.0	1.6	0.0	1.8	0.0	2.0	0.0
Airports	27.9	3.0	28.7	3.1	32.3	3.2	36.1	3.4	39.7	3.5
Railroads	3.2	2.3	3.4	2.4	3.8	2.7	4.2	3.0	4.6	3.3
Total Non-Traffic	40.9	70.9	42.3	68.7	48.7	67.0	55.6	62.9	63.5	68.9

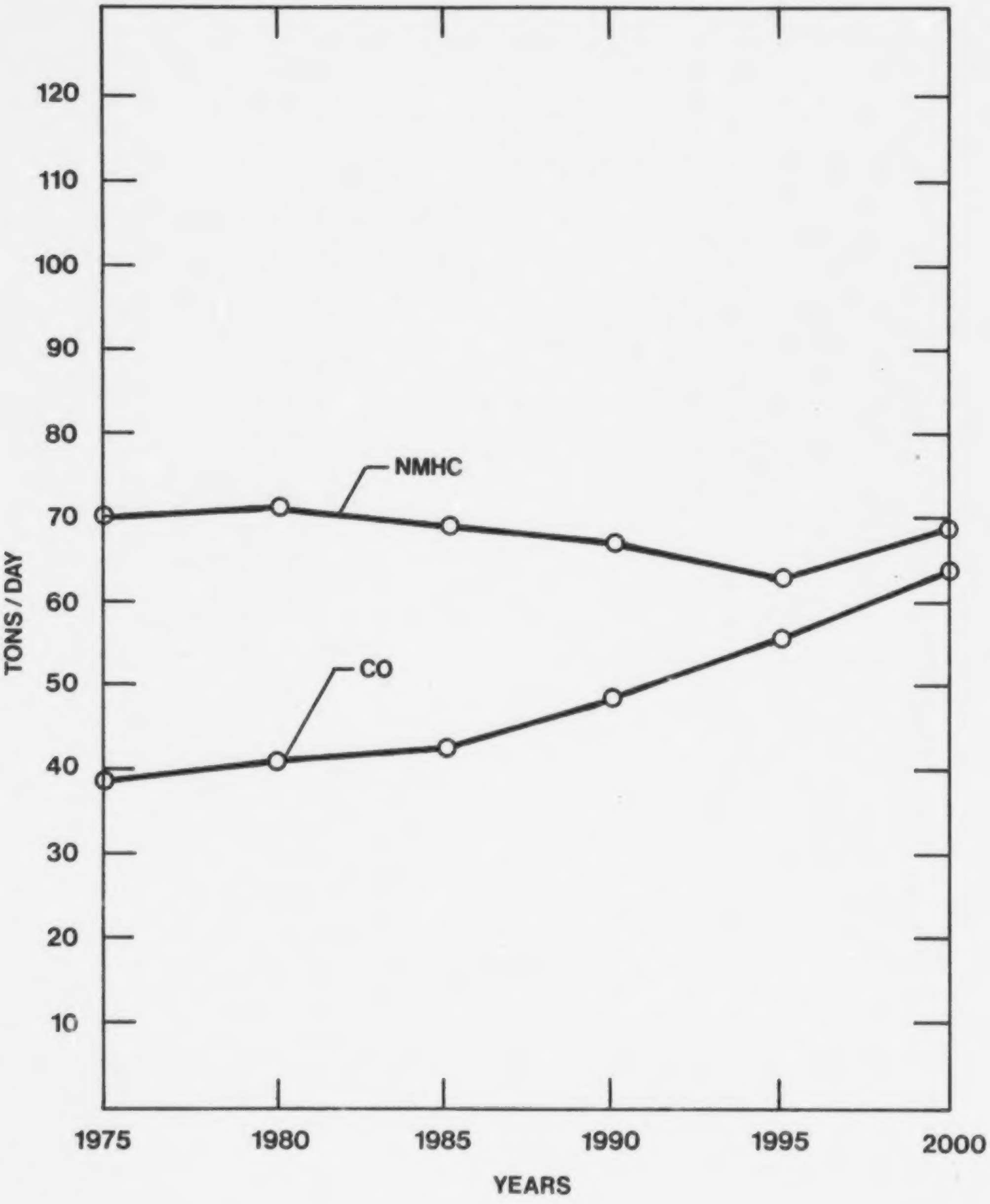


Figure 14. Non-traffic emission trend through 2000.

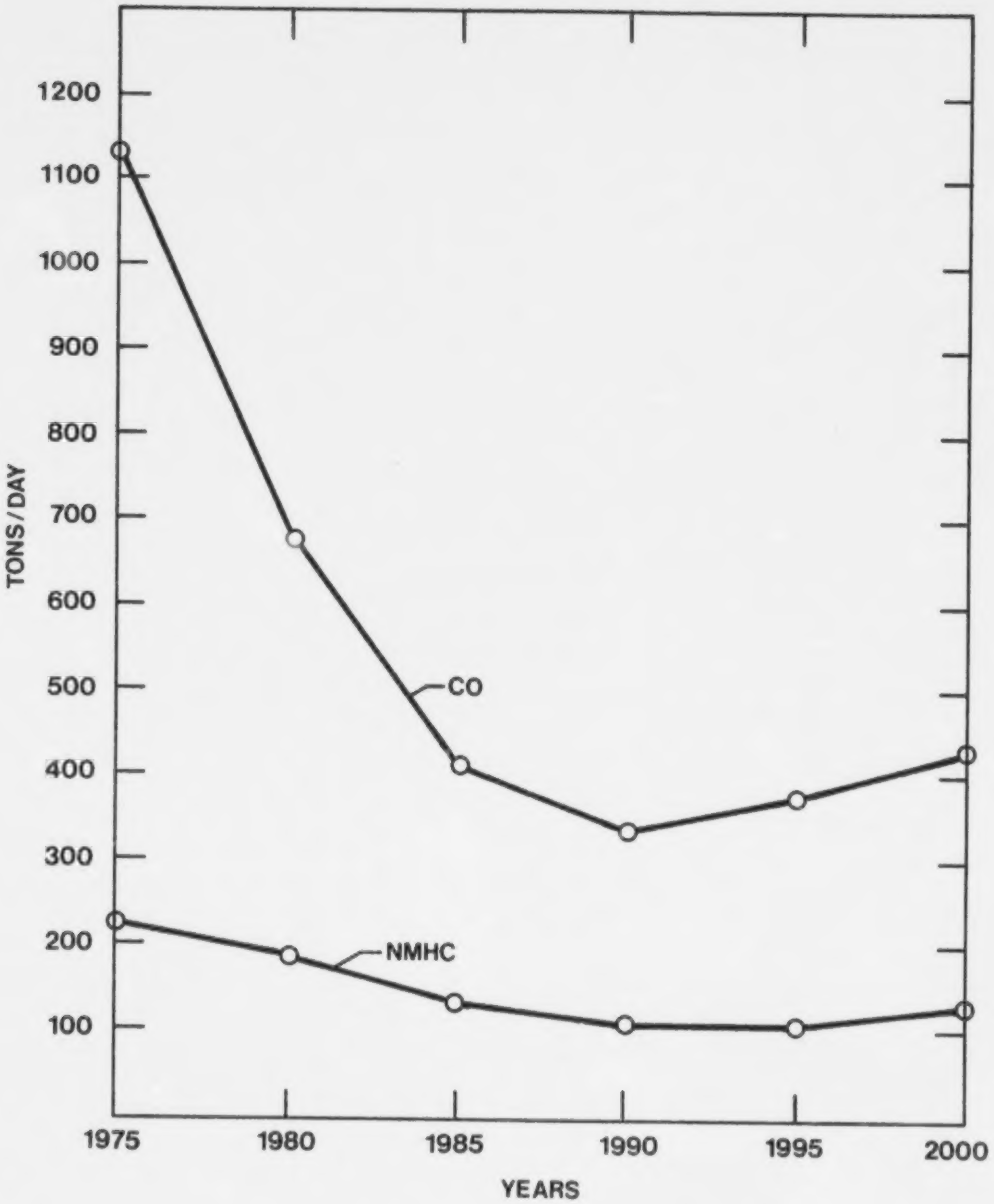


Figure 15. Total emission trend through 2000 for the base case incorporating the following controls: (1) traffic system improvements, (2) improved mass transit, and (3) regional development planning.

EFFECT OF IMPLEMENTATION OF ALTERNATE CONTROL STRATEGIES ON EMISSIONS

Tables 11 and 12 present the effect of control strategies on total study area emissions (traffic and non-traffic). All control strategies affect traffic sources only, with the exception of vapor recovery. The control strategy involving work and driving schedule shifts was projected for 1985 and 1995 because traffic link data for those years was available. Appendix E presents detailed breakdowns of emissions under the various control strategies.

The most effective CO control strategy is periodic maintenance. With this strategy a reduction of 30% in CO emissions, compared to that for the base case, could be achieved by 1995. Inspection/maintenance, the second most effective strategy, would achieve a 14% reduction in total emissions assuming a 16.8% failure rate.

The most effective NMHC control strategy by 1995 is vapor recovery (Phases I and II). An emission reduction of 24% over no controls is projected. An NMHC emission reduction of 16% is projected for periodic maintenance, the second most effective strategy.

Dealer emission control maintenance guarantees and clean air rebate control strategies would be ineffective by themselves. They would, however, be incentive measures supporting the inspection/maintenance or periodic maintenance control strategies.

As mentioned in Chapter V, inspection/maintenance and carpooling are ongoing programs in the Phoenix area. Included in Tables 11 and 12 is the combined effect of these strategies.

Table 11. PROJECTED TOTAL CO EMISSIONS UNDER ALTERNATE CONTROL STRATEGIES.
(tons/day)

Control Strategy	1980			1985			1990			1995			2000		
	Total	Reduction[1]	%	Total	Reduction[1]	%	Total	Reduction[1]	%	Total	Reduction[1]	%	Total	Reduction[1]	%
Base Case[2]	676.0	--	--	406.5	--	--	331.2	--	--	374.2	--	--	430.5	--	-
Inspection/Maintenance	551.3	124.7	18.4	340.5	65.9	16.2	284.3	46.9	14.2	322.0	52.2	13.9	369.6	60.9	14.1
Periodic Maintenance	453.7	222.3	32.9	279.0	127.5	31.4	232.3	98.9	29.9	262.7	111.5	29.8	302.9	127.6	29.6
Dealer Emission Guarantee	676.0	0.0	0.0	406.5	0.0	0.0	331.2	0.0	0.0	374.2	0.0	0.0	430.5	0.0	0.0
Clean Air Rebate	676.0	0.0	0.0	406.5	0.0	0.0	331.2	0.0	0.0	374.2	0.0	0.0	430.5	0.0	0.0
Carpooling	661.1	14.9	2.2	394.8	11.7	2.9	318.3	12.9	3.9	355.6	18.6	5.0	430.5	0.0	0.0
Vapor Recovery	676.0	0.0	0.0	406.5	0.0	0.0	331.2	0.0	0.0	374.2	0.0	0.0	400.7	29.8	6.9
Bicycle Systems	676.0	0.0	0.0	406.5	0.0	0.0	330.4	0.8	0.2	373.2	1.0	0.3	429.2	1.3	0.3
Work and Driving Schedule Shifts	--	--	--	405.5	1.1	0.3	--	--	--	372.8	1.4	0.4	--	--	-
Inspection/Maintenance and Carpooling	539.7	136.3	20.2	331.4	75.1	18.5	275.1	56.1	16.9	307.9	66.3	17.7	342.7	87.8	20.4

[1] From base case

[2] Incorporates the following controls: (1) traffic system improvements, (2) improved mass transit, and (3) regional development planning.

Table 12. PROJECTED TOTAL NMHC EMISSIONS UNDER ALTERNATE CONTROL STRATEGIES.

(tons/day)

Control Strategy	1980			1985			1990			1995			2000		
	Total	Reduction[1]		Total	Reduction[1]		Total	Reduction[1]		Total	Reduction[1]		Total	Reduction[1]	
			%			%			%			%			%
Base Case[2]	185.2	--	--	139.1	--	--	117.8	--	--	117.0	--	--	129.9	--	-
Inspection/Maintenance	147.1	38.1	20.6	116.9	22.2	16.0	102.0	15.8	13.4	101.3	15.7	13.4	112.2	17.7	13.6
Periodic Maintenance	145.6	39.6	21.4	115.2	23.9	17.2	100.6	17.2	14.6	98.6	18.4	15.7	139.1	20.8	16.0
Dealer Emission Guarantee	185.2	0.0	0.0	139.1	0.0	0.0	117.8	0.0	0.0	117.0	0.0	0.0	129.9	0.0	0.0
Clean Air Rebate	185.2	0.0	0.0	139.1	0.0	0.0	117.8	0.0	0.0	117.0	0.0	0.0	129.9	0.0	0.0
Carpooling	181.3	3.9	2.1	136.3	2.8	2.0	114.7	3.1	2.6	112.8	4.2	3.6	123.7	6.2	4.8
Vapor Recovery	181.1	4.1	2.2	129.5	9.6	6.9	100.0	17.8	15.1	88.8	28.2	24.1	98.9	31.0	23.9
Bicycle Systems	185.2	0.0	0.0	139.1	0.0	0.0	117.6	0.2	0.2	116.7	0.3	0.3	129.7	0.2	0.2
Work and Driving Schedule Shifts	--	--	--	139.0	0.1	0.1	--	--	--	117.0	0.0	0.0	--	--	-
Inspection/Maintenance and Carpooling	145.3	39.9	21.5	115.1	24.0	17.3	100.1	17.7	15.0	98.6	18.4	15.7	108.3	21.6	16.6

[1] From base case.

[2] Incorporates the following controls: (1) traffic system improvements, (2) improved mass transit, and (3) regional development planning.

VII. MODELING OF CO AIR QUALITY

The APRAC-II model was used in the simulation of severe CO air quality in the Phoenix study area. A description of the APRAC-II model appears in Appendix F.

CASE SELECTION

During the base year, 1975, the highest 8-hour average CO reading was 34 mg/m^3 (30 ppm), which was recorded at monitoring Site 3 on 13 November 1975. The locations of Site 3 and other air quality/meteorological monitoring stations in Phoenix were presented in Figure 3. The second highest reading was 30 mg/m^3 (26 ppm), observed on 4 November, 1975, also at Site 3.

In determining these highest and second highest 8-hour values, the Environmental Protection Agency's recommendation in Guidelines for the Interpretation of Air Quality Standards (U.S. EPA, 1974) was followed.

Communications with officials of the Arizona Department of Health Services (ADHS) indicated that there was extensive controlled forest burning during the 13-14 November period, which was significant in terms of poor air quality but not a representative period to simulate automobile generated air pollution. Consequently, data for 13 November was discarded.

Meteorological conditions during 4-5 November, 1975, the day with the second highest 8-hour average, were very conducive to high carbon monoxide concentrations. Consequently, the period beginning at 1900 on 4 November during which the 8-hour carbon monoxide average was 30 mg/m^3 (26 ppm) was singled out for modeling.

APRAC-II INPUTS

Simulation of carbon monoxide air quality by means of the APRAC-II model requires two primary types of inputs – emissions and meteorology.

Emissions

The APRAC-II model requires emissions from each link in a roadway network for each hour of a day. These emissions were computed by means of AVSUP5, as discussed in Chapter IV. In addition to emissions from primary traffic for each link, the model also needs emissions from secondary traffic and non-automobile sources to be supplied in grid form. This emissions data, discussed in Chapter IV, was distributed into 2200 grids, one square mile each, defined by locating the point x = 0 at 2.5 miles west of Jackrabbit Trail and the point y = 40 at 4.5 miles north of Pinnacle Peak Road. The emissions grid map is presented in Figure 16.

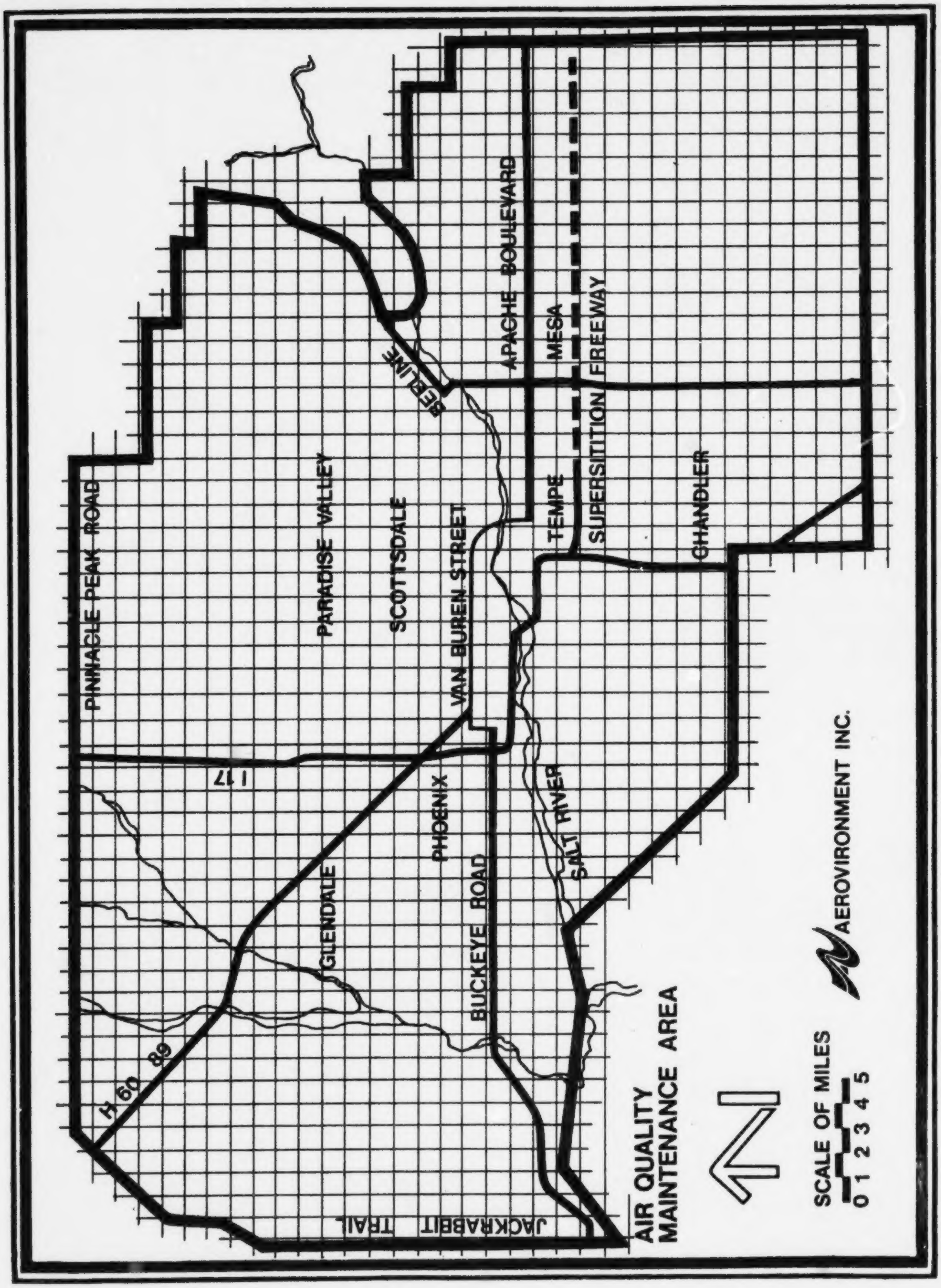
Meteorology

On 4-5 November 1975, the meteorology in Phoenix was dominated by a large high pressure system centered around northeastern Utah (Figure 17). The 500-millibar synoptic charts for 4 November showed descending air over Arizona. Stagnation conditions were reported throughout Phoenix during the 8-hour period beginning at 1900 on 4 November. Winds, when detectable, were light and generally from the north.

Wind data at receptor points used in the calculation of carbon monoxide concentration was determined from wind records at six wind stations. Actual data used is presented in Table 13. The minimum wind speed acceptable to APRAC-II is 1 m/s. This accounts for the many 1 m/s speeds in Table 13, which were actually calm.

To determine atmospheric stability, weather observations at Sky Harbor Airport were used. The wind data reported at Sky Harbor was not an hourly averaged reading, but rather, represented an instantaneous observation on the hour. Since this information was not representative of transport conditions during a one-hour period, wind information at Sky Harbor was not used to determine the transport wind at receptors. This wind speed data was used in conjunction with other parameters in the determination of atmospheric stability, however. This data is presented in Table 14.

Since there was no mixing height information available for this period, a mixing correction factor of 15 m was used because this factor resulted in excellent correlation between observed and predicted values and minimized the difference between observed and predicted concentrations. In essence, one can say that the mixing height was adjusted so as to provide a best-fit to the data.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BEELINE
APACHE BOULEVARD
MESA
TEMPE
SUPERSITITION FREEWAY
CHANDLER
I 17
PHOENIX
GLENDALE
BUCKEYE ROAD
SALT RIVER
JACKRABBIT TRAIL
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AEROVIRONMENT INC.

Figure 16. Emissions grid map.

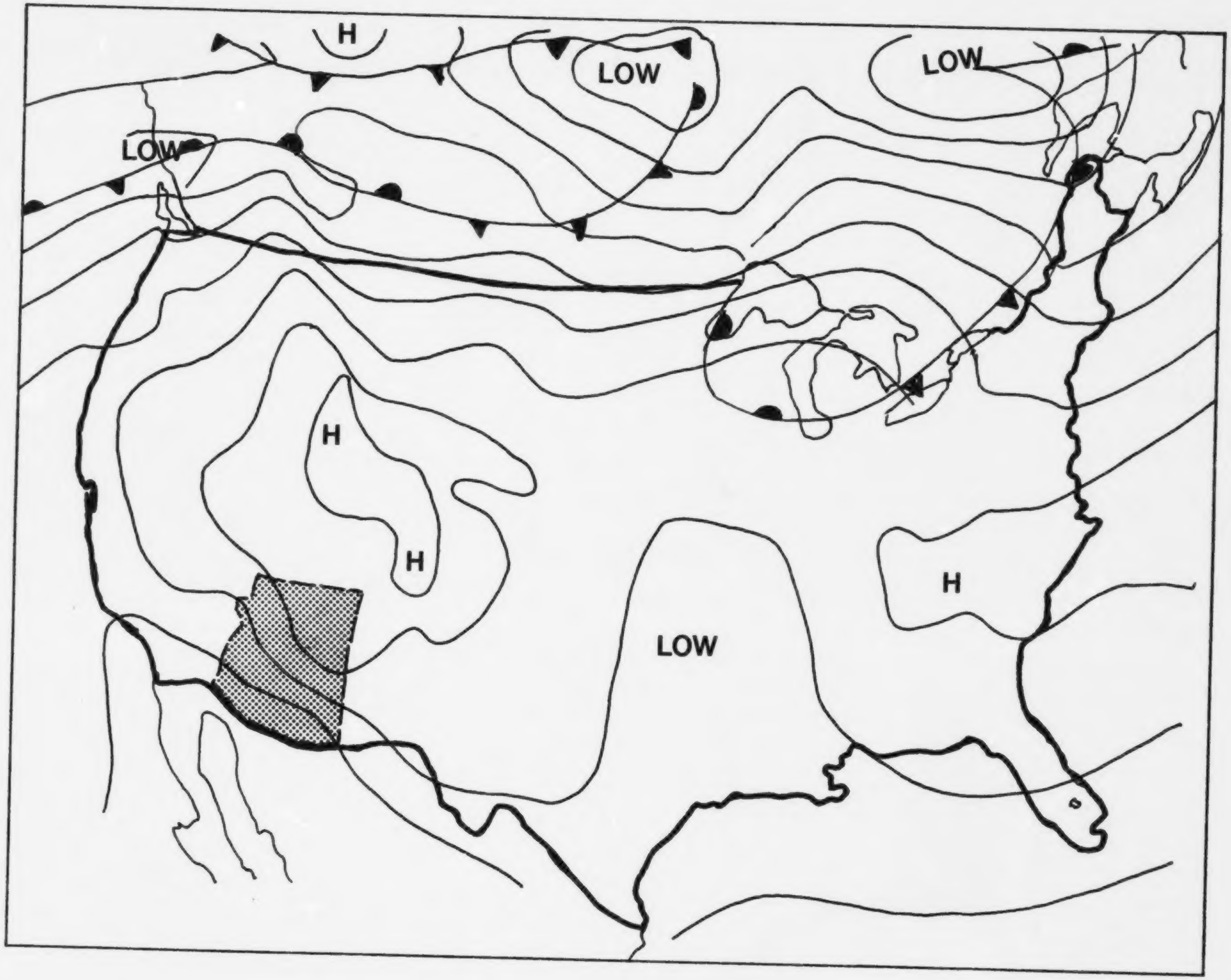
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Figure 17. Surface weather map at 7:00 a.m. EST on 4 November 1975.

Table 13. WIND DATA USED FOR THE APRAC-II SIMULATIONS.

	Site	1		2		4		6		8		9	
Date	Hour	WD	WS*	WD	WS	WD	WS	WD	WS	WD	WS	WD	WS
11/4	19	360	1.3	360	1.0	360	1.8	30	2.2	25	1.3	45	1.8
	20	360	1.3	310	1.0	360	2.2	360	2.2	25	1.0	45	2.2
	21	360	1.3	360	1.0	10	1.8	5	2.7	340	1.0	45	2.7
	22	360	1.0	310	1.0	20	2.2	355	2.7	360	1.3	45	3.1
	23	360	1.3	310	1.3	15	1.3	315	1.8	10	1.0	35	3.1
11/5	00	360	1.0	310	1.0	10	1.8	285	1.3	340	1.0	30	3.6
	01	10	1.3	310	1.0	30	1.3	320	1.0	340	1.0	20	2.2
	02	35	1.8	30	1.3	30	1.0	320	1.0	340	1.0	20	3.1

* Meters/sec

Table 14. METEOROLOGICAL DATA (AT SKY HARBOR AIRPORT) USED TO CALCULATE ATMOSPHERIC STABILITY.

Date	Hour	Wind Speed (Knots)	Temperature (K)	Cloud Cover (tenths)
11/4	19	6.0	300	0
	20	5.0	297	0
	21	4.0	296	0
	22	3.0	295	0
	23	5.0	294	0
11/5	00	3.0	293	0
	01	6.0	293	0
	02	6.0	291	0

APRAC-II VERIFICATION

The 8-hour CO air quality beginning at 1900 on 4 November 1975 was simulated to verify the predictive accuracy of the APRAC-II Model. Concentrations were calculated at all locations which monitored carbon monoxide. Both predicted and observed values are presented in Table 15. Figure 18 shows a linear regression plot of observed versus predicted concentrations. The correlation coefficient was 0.97. The intercept was -0.6 while the slope was 2.56.

Although there were only six data points, (data was not available at one of the seven stations measuring CO), the correlation coefficient was significant. Such a good fit indicated that the model was able to predict reasonably well the spatial variability of carbon monoxide during the selected episodic period in Phoenix.

To derive absolute values from predictions, a correction factor of 2.47 was used. This correction factor was calculated as follows:

$$\text{Correction factor} = \frac{\Sigma XY}{\Sigma X^2} ,$$

where X's are predicted concentrations and Y's are observed concentrations.

Adjusted predictions and observed concentrations are presented in Table 16 and Figure 19. The standard error of estimate[1] was 2.0 ppm[2]. This value is less than 10% of the highest predicted concentration of 23.3 ppm and should be considered acceptable.

Overall, the model performed quite well in simulating "hot spots" and high carbon monoxide concentrations observed at the six monitoring sites during an episodic period. Thus, in simulating the air quality under identical meteorological conditions for the future, the APRAC model can be used with reasonable confidence and the predictions should be considered good to within ± 2 ppm ($\pm$ 2 mg/m^3).

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[1] Standard error of estimate = $\sqrt{\Sigma (Y_a - Y)^2/N}$ where Y_a is the adjusted value and Y the corresponding observed value.

[2] Concentrations are presented in ppm for CO. To convert from ppm to mg/m^3, multiply the value by 1.15.

Table 15. A COMPARISON OF PREDICTED AND OBSERVED 8-HOUR AVERAGE CO CONCENTRATIONS (ppm).

Site	Observed Value	Predicted Value
1	10.8	6.1
3	26.1	9.5
4	2.1	.7
6	2.0	1.2
8	4.8	2.0
9	1.3	.5

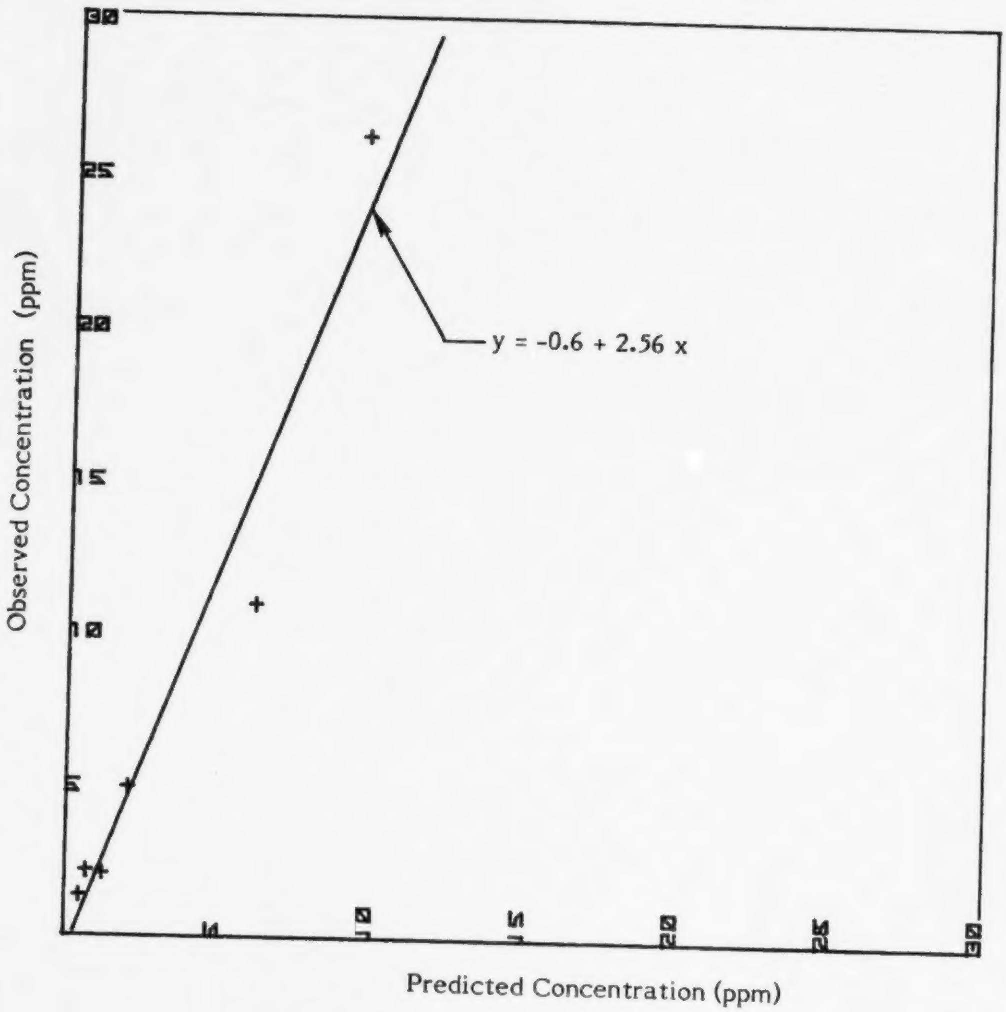

Figure 18. A linear regression plot of observed versus predicted concentrations.

Table 16. A COMPARISON OF OBSERVED VALUES AND ADJUSTED PREDICTIONS OF 8-HOUR CO CONCENTRATIONS (ppm).

Site	Observed Value	Adjusted Prediction
1	10.8	14.9
3	26.1	23.3
4	2.1	1.7
6	2.0	3.0
8	4.8	4.9
9	1.3	1.2

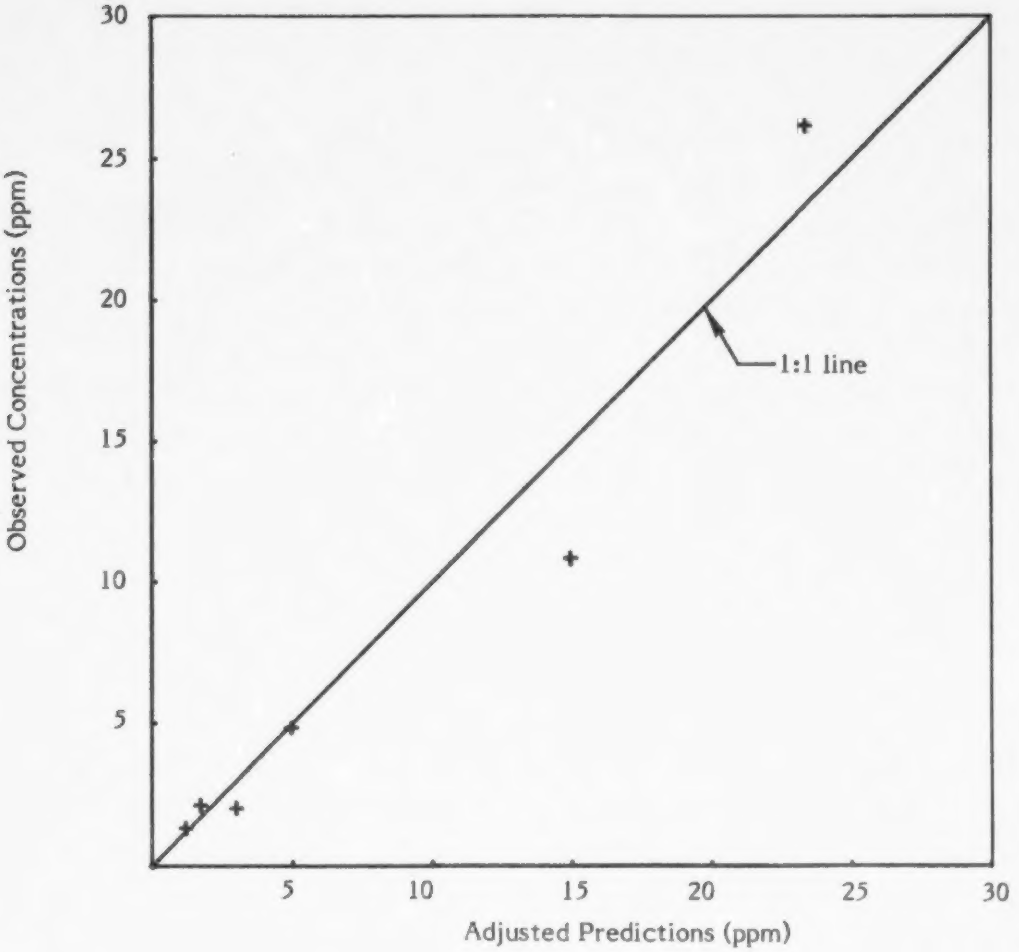

Figure 19. A scatter diagram showing observed data versus adjusted predictions.

CO AIR QUALITY IN 1975, 1985 AND 1995 WITHOUT ADDITIONAL CONTROL STRATEGIES[1]

Figure 20 presents predicted concentration isopleths of the severe-case 8-hour CO concentrations in Phoenix in 1975. Highest values were predicted a couple of miles south of the Phoenix commercial district (Central and Van Buren). The slight southward displacement of the CO peak from the traffic hot spots is a direct consequence of the light northerly winds that were observed during this period. Exceedances of the 8-hour standard of 9 ppm were predicted to occur in an extensive area bounded to the east by 56th Street, to the west by 51st Avenue, to the north by Indian School Road, and to the south by the Gila River Indian Reservation. The highest peak was 32.3 ppm, approximately four times the 8-hour CO standard.

Isopleths of predicted 8-hour average CO concentrations in 1985 and 1995 without any additional control strategies (base case) are shown in Figure 21 and 22 respectively. Locations of CO hot spots were identical to those predicted for the 1975 case, which was to be expected since the same meteorology was assumed. Peak readings in 1985 and 1995 were predicted to be 11.7 ppm and 8.6 ppm respectively. Exceedances of the 8-hour CO standard were predicted for the 1985 case but not for the 1995 case.

The gradual improvement in the 8-hour CO air quality from 1975 to 1985 is attributed to a gradual reduction in CO emissions for the same time period. This reduction is largely related to the assumption that newer cars emit less pollutants than older cars, an assumption implicit in emission factors in Supplement 5 of AP-42. Therefore, as time goes by, even though there would be more cars on the road, the total emissions generated by these newer cars would be less than emissions from older cars that were being replaced.

This improvement is expected to continue until 1990, by which time all cars on the road will be equipped with similar emission control devices. Beyond 1990, emissions generated by motor vehicles will increase at a rate proportional to population growth, unless further controls are introduced in the future. This trend was illustrated in Figure 13. By 1995, CO emissions in the area would result in a peak CO concentration of 8.6 ppm as discussed.

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[1] It was assumed that traffic system improvements, improved mass transit and regional development planning are ongoing activities. Without additional control strategies here refers to the base case when only these three control strategies are implemented.

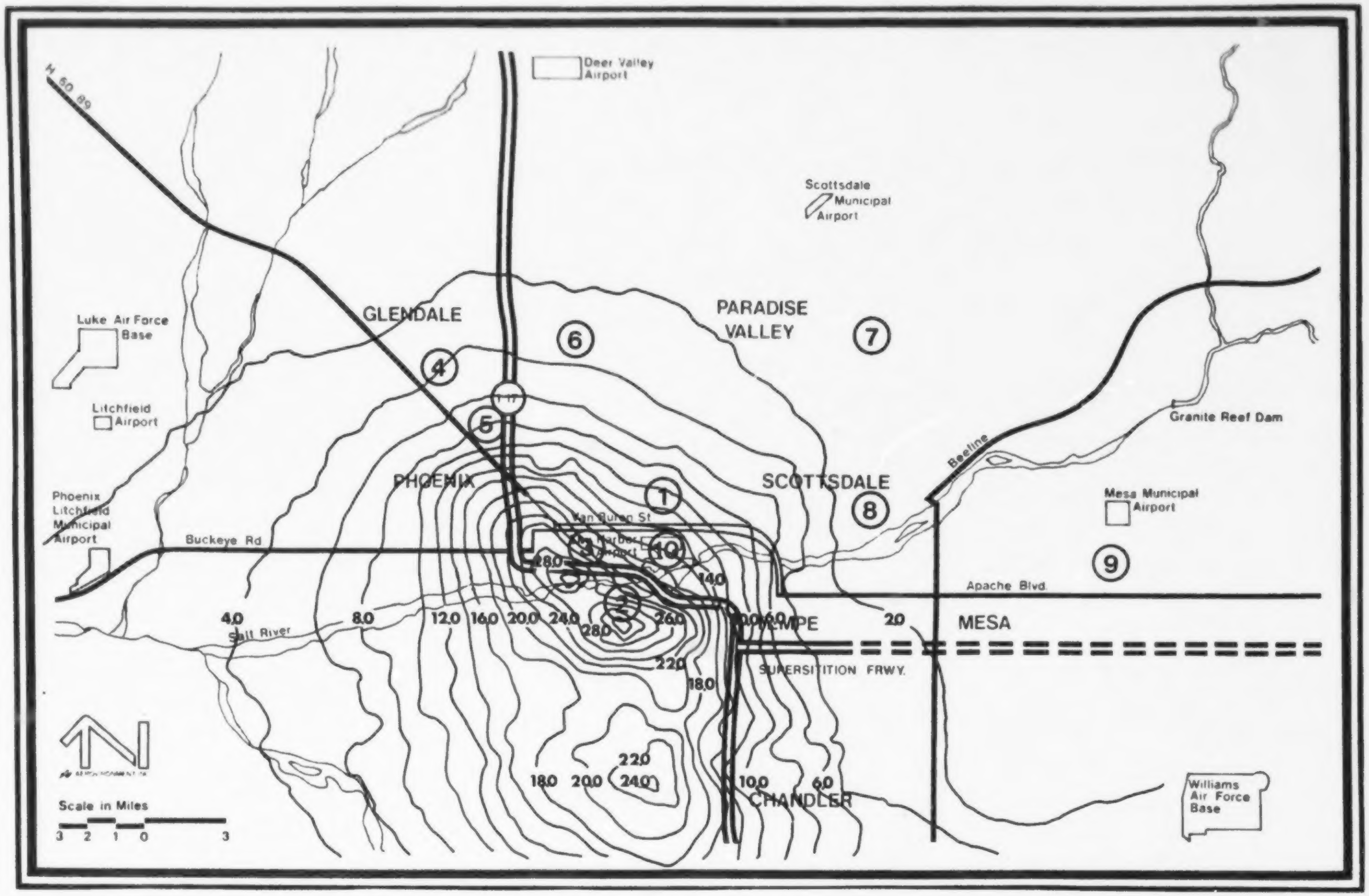
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Figure 20. Isopleths of predicted 8-hour CO concentrations in ppm for the 1975 case. The locations of the monitoring sites are shown.

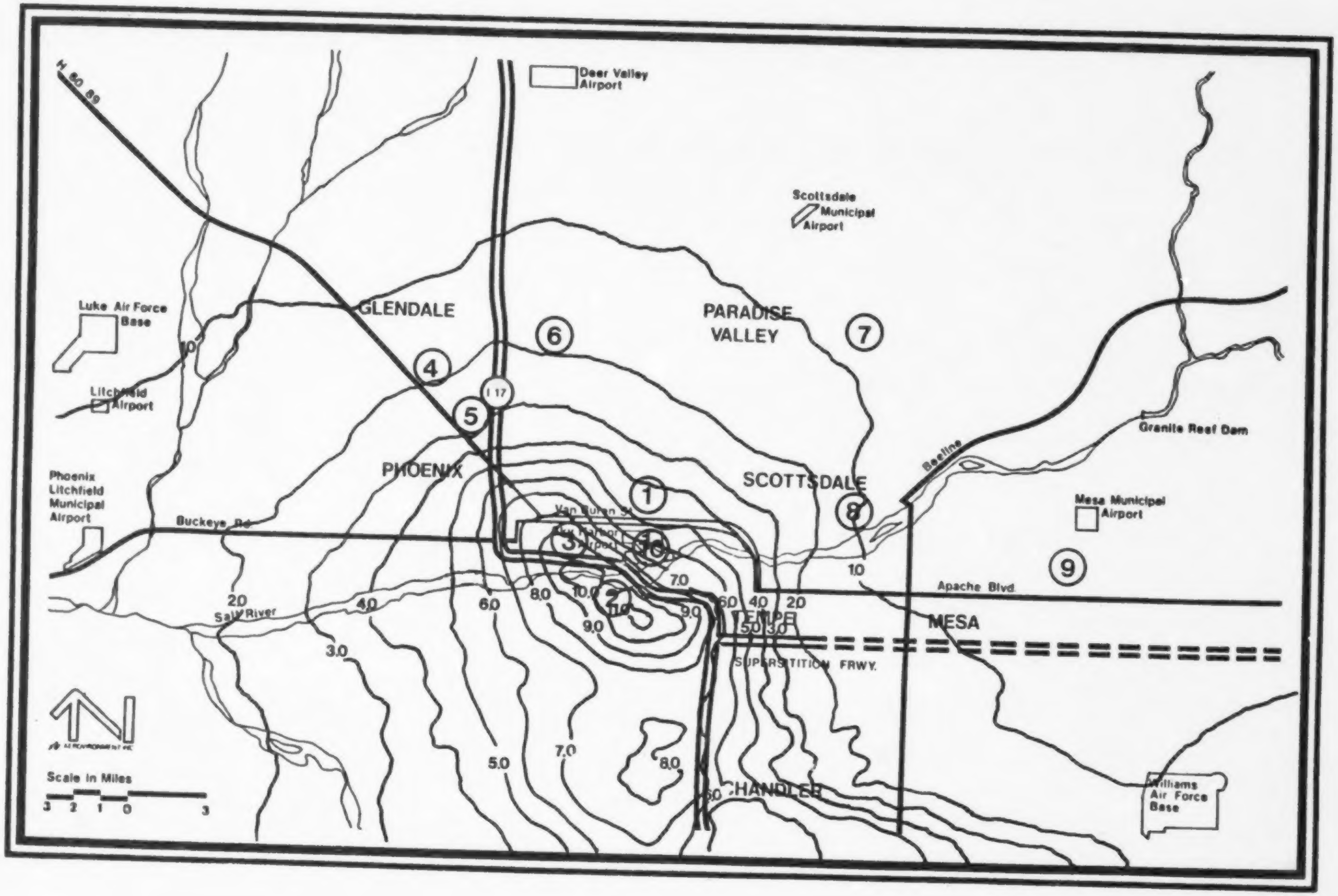
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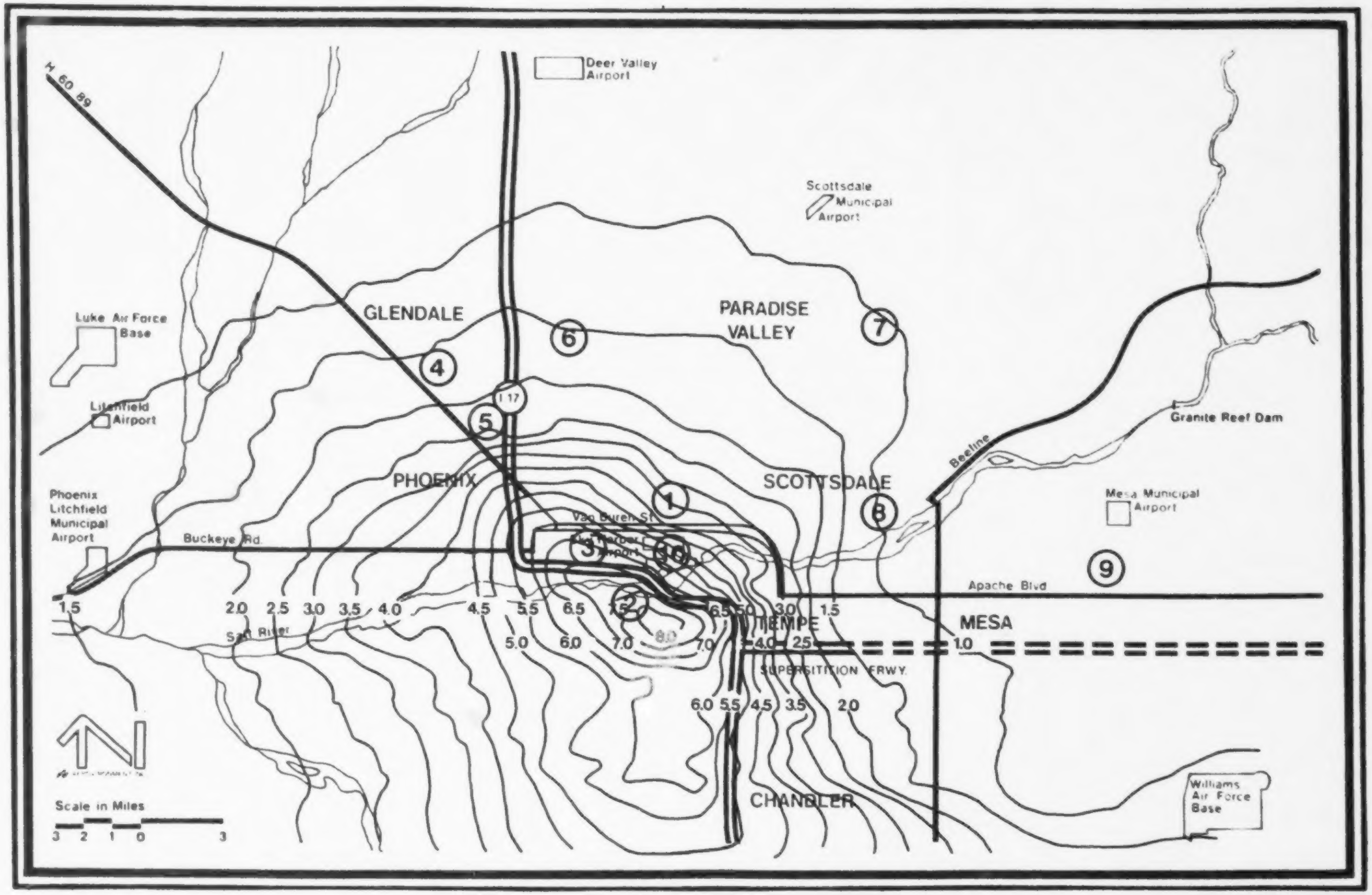
Figure 21. Isopleths of predicted 8-hour average CO concentrations in ppm for 1985 without 8 additional control strategies (base case). The locations of the monitoring sites are shown.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Scale in Miles
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Figure 22. Isopleths of predicted 8-hour average CO concentrations in ppm for 1995 without 8 additional control strategies (base case). The locations of the monitoring sites are shown.

Concentrations were also predicted at locations where CO measurements were taken in 1975. They are given in Table 17. Highest concentrations were predicted at Stations 1, 2 and 3 in downtown Phoenix. Station 9, in Mesa, was predicted to have the lowest concentration amongst the seven monitoring sites. Exceedances were predicted at three stations in 1975 and at none in 1985 or 1995.

CO AIR QUALITY IN 1985 AND 1995 WITH THE IMPLEMENTATION OF INSPECTION/MAINTENANCE AND CARPOOLING

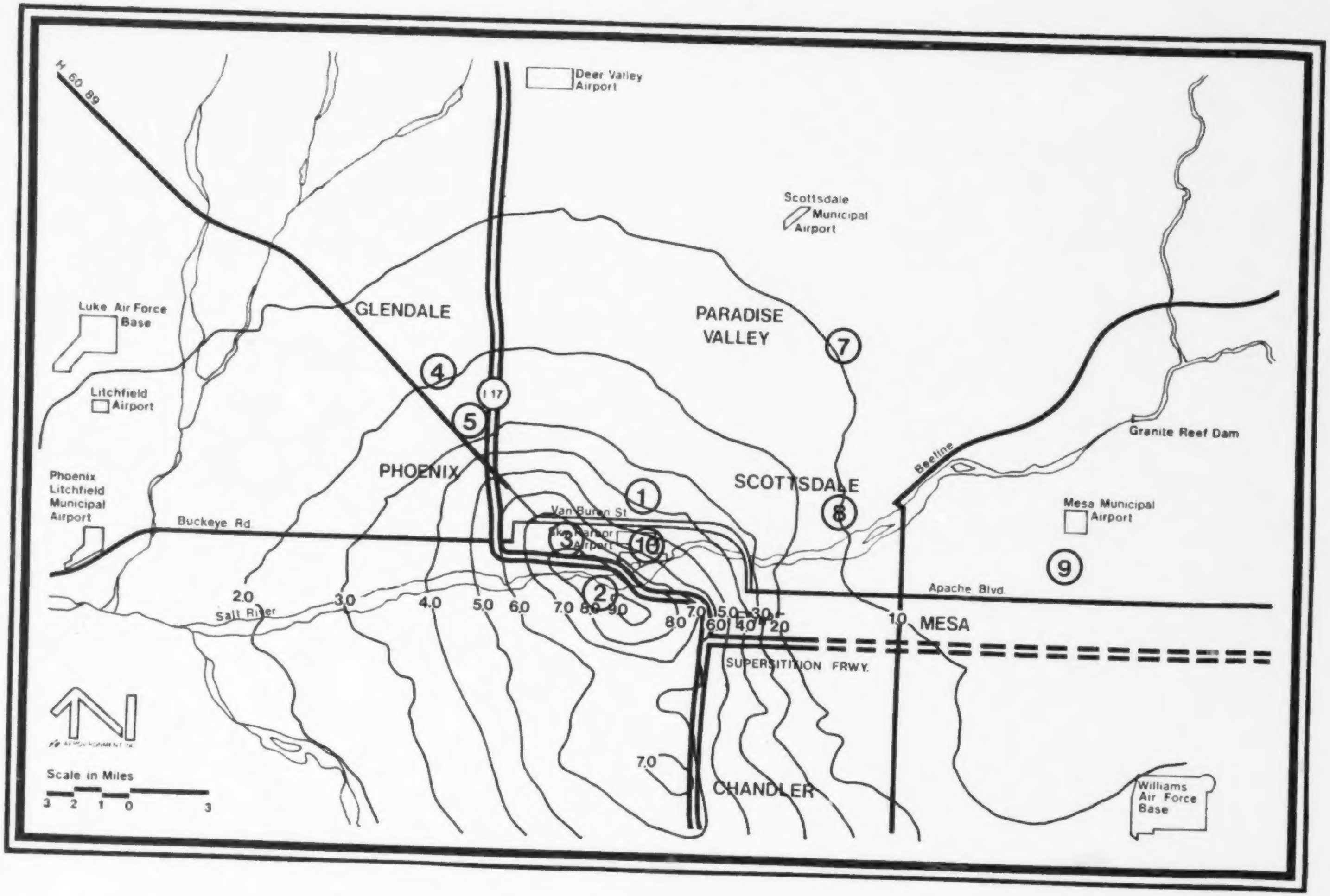
The inspection/maintenance program and voluntary carpooling are strategies that are currently being implemented in Phoenix. It is essential to determine whether their existence alone is all that is required to maintain the 8-hour CO standard. With this in mind, the APRAC-II model was applied to simulate severe case CO air quality in 1985 and 1995 in Phoenix when these two strategies are allowed to continue indefinitely. Added to these strategies are traffic system improvements, improved mass transit and regional development planning, all of which are part of an on-going planning process.

The only change in model inputs from the model runs presented in the last chapter was automobile emissions. A 26% reduction in CO emissions from light-duty vehicles in 1985 was taken into account. (With inspection/maintenance alone, there would be a reduction of 22% in CO emissions from light-duty vehicles. With carpooling alone, the reduction would be 5%. The effect of implementing carpooling on top of inspection/maintenance was a reduction of 26% in CO emissions.) At the same time, an 11% reduction in CO emissions from heavy-duty vehicles, resulting from the inspection/maintenance program, was also considered. Emissions reductions attributable to the inspection/maintenance program was not expected to increase in 1995. However, it was assumed that increases in carpooling would result in a 12% reduction in CO emissions from light-duty vehicles by 1995. Thus, in 1995, emissions from light-duty vehicles would be reduced by 31% while those from heavy-duty vehicles by 11%.

Model results are presented in Figures 23 and 24. Again, because the same severe meteorological conditions were assumed, the spatial distribution of CO concentrations remained very similar to that in Figure 20. With the continuation of the inspection/maintenance and carpooling programs, the highest CO peak in 1985 would drop from 11.7 ppm to 9.7 ppm. The corresponding drop in 1995 was predicted to be 1.5 ppm, i.e., from 8.6 ppm to 7.1 ppm.

Table 17. PREDICTED SEVERE-CASE 8-HOUR AVERAGE CO CONCENTRATIONS (PPM) AT MONITORING SITES IN 1975, 1985 AND 1995 FOR THE BASE CASE. (NATIONAL STANDARD: 9 PPM).

Monitoring Site	1975	1985	1995
1	14.9	5.2	4.5
2	21.9	8.4	6.5
3	23.3	8.5	6.2
4	1.7	1.2	1.2
6	3.0	1.7	1.5
8	4.9	2.2	2.0
9	1.2	0.8	0.8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GLENDALE
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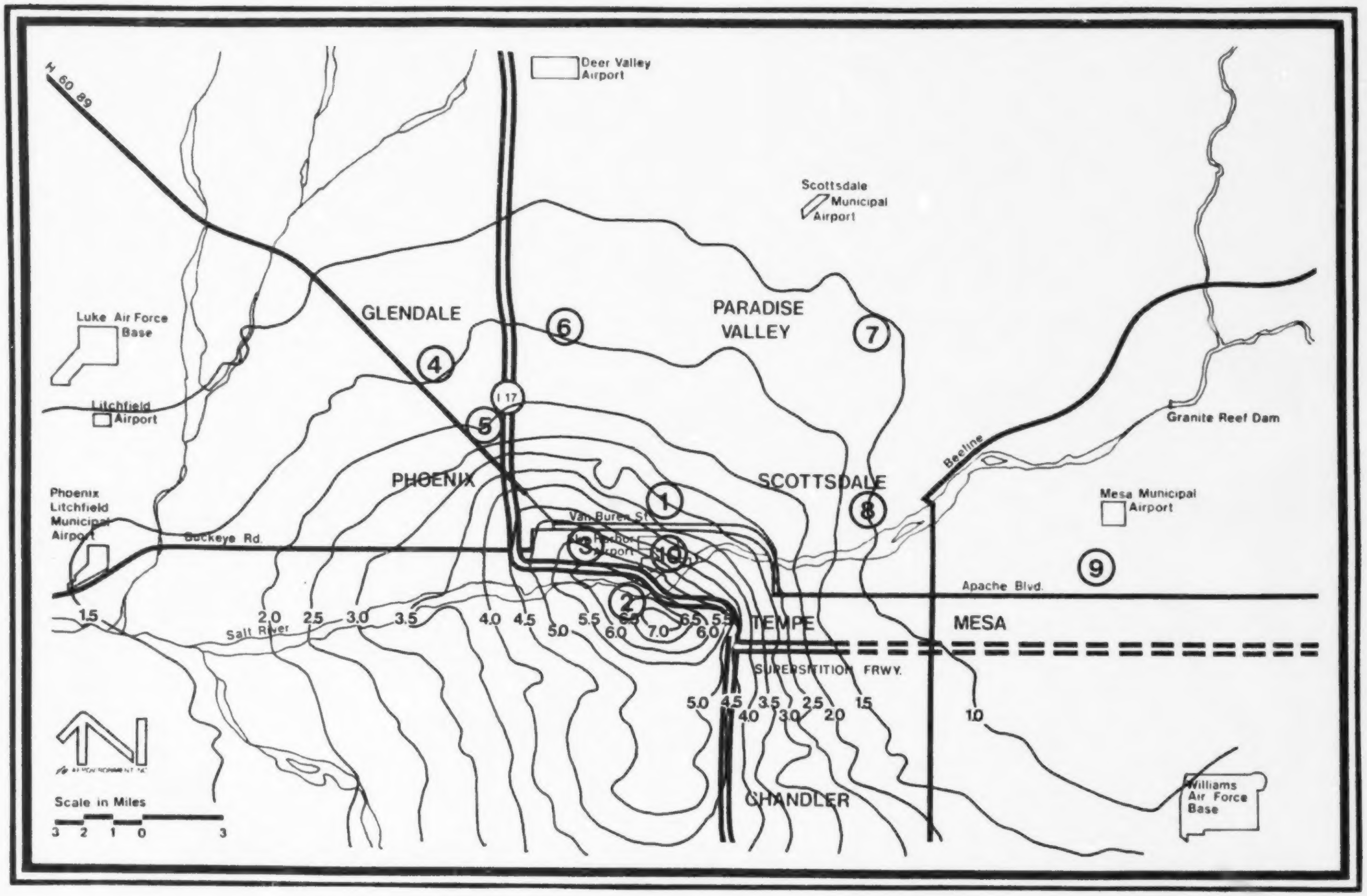
Litchfield Airport
I 17
Granite Reef Dam
Beeline
Phoenix Litchfield Municipal Airport
PHOENIX
SCOTTSDALE
Mesa Municipal Airport
Buckeye Rd
Van Buren St
Sky Harbor Airport
Apache Blvd
Salt River
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
8.0
7.0
5.0
3.0
6.0
4.0
2.0
1.0
MESA
SUPERSTITION FRWY.
7.0
CHANDLER
Williams Air Force Base
Scale in Miles
3 2 1 0 3
1
2
3
4
5
7
8
9
10

Figure 23. Isopleths of predicted 8-hour CO concentrations in ppm for 1985 with the implementation of inspection/maintenance and carpooling. The locations of the monitoring sites are shown.


H 60 89
Deer Valley Airport
Scottsdale Municipal Airport
Luke Air Force Base
GLENDALE
PARADISE VALLEY
Litchfield Airport
I 17
Granite Reef Dam
Beeline
Phoenix Litchfield Municipal Airport
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SCOTTSDALE
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6.0
Salt River
TEMPE
MESA
SUPERSTITION FRWY.
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
CHANDLER
Williams Air Force Base
Scale in Miles
3 2 1 0 3

Figure 24. Isopleths of predicted 8-hour CO concentrations in ppm for 1995 with the implementation of inspection/maintenance and carpooling. The locations of the monitoring sites are shown.

A comparison of predicted concentration at monitoring sites with and without these strategies is shown in Table 18. When these two strategies are maintained, there would not be any violation of the 8-hour standard in 1985 and 1995 at existing monitoring sites.

CO AIR QUALITY IN 1985 AND 1995 WITH THE IMPLEMENTATION OF OTHER CONTROL STRATEGIES

No explicit model runs were performed to assess the effectiveness of other control strategies. However, CO air quality resulting from the implementation of such control strategies can be inferred from model results presented in the last section.

A comparison of the ratios of predicted peak CO readings to the corresponding CO emissions for the 5 scenarios modeled is presented in Table 19. It is evident that for each year, the ratio is a constant. Variations of this ratio with time are attributed to changes in the distribution of emissions, primarily from changes in the transportation network from 1985 to 1995. Thus, knowing the total emissions that would result after the implementation of a certain control strategy, the peak CO reading for a particular year can be obtained by multiplying that emissions value by the ratio for the same year.

Emissions in Phoenix in 1985 and 1995 with different control strategies implemented were discussed in Chapter VI. In addition to traffic system improvements, improved mass transit and regional development planning, the control strategies that would result in significant CO emission reductions are inspection/maintenance, periodic maintenance, and carpooling. Using peak CO reading/CO emissions ratios of 0.029 for 1985 and 0.023 for 1995, peak CO readings that would result from different control strategies were calculated. Table 20 shows the results.

The effect of a combination of inspection/maintenance and carpooling was discussed in the last section, but is presented again in Table 20 for comparison. The implementation of inspection/maintenance or carpooling alone in addition to the three basic control strategies (traffic system improvements, improved mass transit, and regional development planning) would not result in the attainment of the 8-hour CO standard of 9 ppm by 1985. Periodic maintenance alone and periodic maintenance with carpooling would both result in the attainment of the standard by 1985.

Table 18. A COMPARISON OF SEVERE-CASE 8-HOUR CO READINGS (PPM) AT MONITORING SITES WITH AND WITHOUT THE IMPLEMENTATION OF INSPECTION/MAINTENANCE AND CARPOOLING. (NATIONAL STANDARD: 9PPM).

	1985		1995	
Monitoring Site	Without I/M & Carpooling (Base Case)	With I/M & Carpooling	Without I/M & Carpooling (Base Case)	With I/M & Carpooling
1	5.2	4.4	4.5	3.7
2	8.4	7.0	6.5	5.4
3	8.5	7.1	6.2	5.2
4	1.2	1.1	1.2	1.1
6	1.7	1.5	1.5	1.3
8	2.2	1.9	2.0	1.7
9	0.8	0.8	0.8	0.8

Table 19. THE RATIOS OF PEAK CO READINGS TO CO EMISSIONS DERIVED FROM THE FIVE APRAC-II RUNS.

Year	Controls[1]	Peak CO[2] Reading (ppm)	Emissions (tons/day)	Ratio
1975	None	32.5	1125.0	0.029
1985	1,2&3	11.7	406.5	0.029
1985	1,2,3,4&5	9.7	331.4	0.029
1995	1,2,&3	8.6	374.2	0.023
1995	1.2,3,4&5	7.1	307.9	0.023

[1] Control 1: Traffic systems improvement
2: Improved mass transit
3: Regional development planning
4: Inspection/maintenance
5: Carpooling

[2] National CO 8-hour standard is 9 ppm.

Table 20. PREDICTED PEAK 8-HOUR CO READINGS IN 1985 AND 1995 FOR DIFFERENT CONTROL STRATEGIES.

Control Strategy	1985		1995	
	Emissions[2] (tons/day)	Peak CO[3] Reading (ppm)	Emissions (tons/day)	Peak CO Reading (ppm)
Base Case[1]	406.5	11.7	374.2	8.6
Base Case plus Inspection/Maintenance (I/M)	340.5	9.9	322.0	7.4
Base Case plus Periodic Maintenance (PM)	279.0	8.1	262.7	6.0
Base Case plus Carpooling	394.8	11.4	355.6	8.2
Base Case plus PM and Carpooling	271.4	7.9	250.5	5.8
Base Case plus I/M and Carpooling	331.4	9.7	307.9	7.1

[1] Base Case includes traffic system improvements, improved mass transit and regional development planning.

[2] Total emissions corresponding to a peak 8-hour CO reading of 9 ppm would be 310.3 tons/day in 1985 and 391.3 tons/day in 1995.

[3] National CO 8-hour standard is 9 ppm.

PROJECTED CO AIR QUALITY IN 1980, 1990 AND 2000

Modeling of CO air quality using APRAC-II to obtain the multiplicative factor (ratio of CO peak reading to CO emissions) for 1980, 1990 and 2000 was not possible because of lack of detailed traffic data. Since the multiplicative factors for 1975 and 1985 were both equal to 0.029, it was assumed that the same factor would be appropriate for 1980. Lacking better information, the multiplicative factor for 1990 (0.026) was interpolated from factors for 1985 and 1995. Here, it was assumed that there would be gradual changes in the transportation network from 1985 to 1995. The multiplicative factor for 2000 was taken to be the same as that for 1995. Here, it was assumed that there would not be any changes in the transportation network from 1995 to 2000.

Total CO emissions for Phoenix in 1980, 1990, and 2000 as well as peak 8-hour CO readings with or without additional control strategies other than traffic system improvements, improved mass transit and regional development planning are presented in Table 21. No data was presented for the implementation of dealer emissions control maintenance guarantee, clean air rebate, vapor recovery, bicycle systems and work and driving schedule shifts because there were insignificant reductions in the resultant emissions.

The predicted peak CO readings in 1980 were all higher than the 8-hour CO standard while all predicted peak CO readings in 1990 were below the standard. In 2000, the peak value was higher than the standard for the base case, i.e., with only traffic system improvements, improved mass transit and regional development planning, but the peak reading with any additional control strategy was lower than the standard.

PREDICTED ATTAINMENT YEARS FOR CO

Figure 25 shows the relative magnitude of the predicted peak 8-hour CO readings for the various study years and their relation to the National Standard (9 ppm). This figure was used to approximate the years of attainment of the standard with various combinations of control strategies. These attainment years are presented in Table 22 to serve as an aid in assessing the relative effectiveness of the various control strategy combinations. Bearing in mind that model predictions are good to ± 2 ppm, the year of attainment could change by as much as ± 3 years.

Table 21. CO EMISSIONS AND PEAK 8-HOUR CO READINGS IN 1980, 1990 AND 2000 FOR DIFFERENT CONTROL STRATEGIES

	1980		1990		2000	
Control Strategy	Emissions[2] (tons/day)	Peak CO[3] Reading (ppm)	Emissions (tons/day)	Peak CO Reading (ppm)	Emissions (tons/day)	Peak CO Reading (ppm)
Base Case[1]	676.0	19.6	331.2	8.6	430.2	9.9
Base Case plus Inspection/Maintenance	551.3	16.0	284.3	7.4	364.3	8.4
Base Case plus Periodic Maintenance	453.7	13.1	232.3	6.0	302.9	7.0
Base Case plus Carpooling	661.1	19.1	318.3	8.3	400.7	9.2
Base Case plus I/M and Carpooling	539.7	15.7	275.1	7.1	342.7	7.9
Base Case plus PM and Carpooling	444.1	12.9	224.6	5.8	283.9	6.5

[1] Base Case includes traffic system improvements, improved mass transit and regional development planning.

[2] Total emissions corresponding to a peak 8-hour CO reading of 9 ppm would be 310.3 tons/day in 1980, 346.2 tons/day in 1990, and 391.3 tons/day in 2000.

[3] National CO 8-hour standard is 9 ppm.

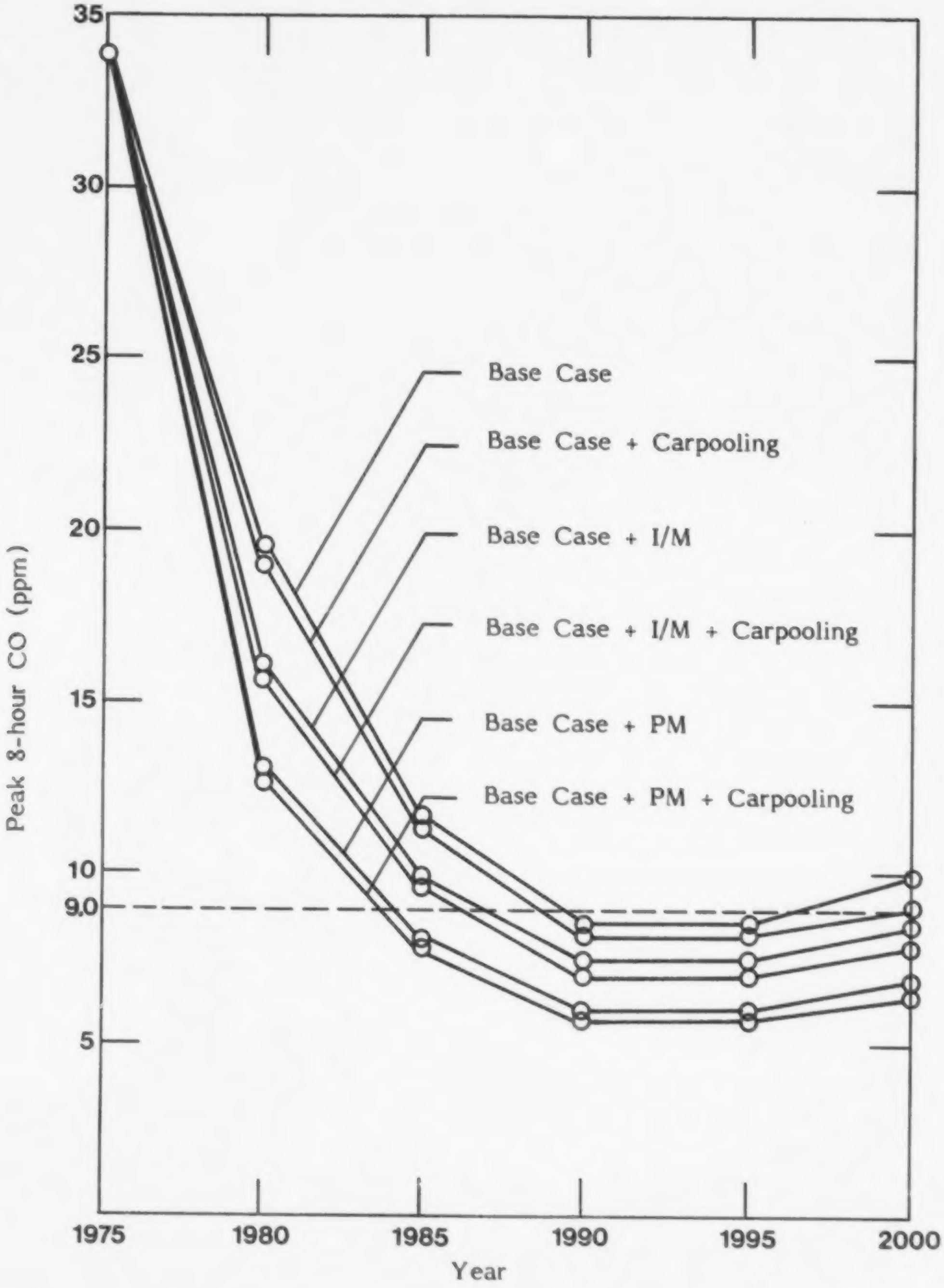

Figure 25. Predicted peak 8-hour CO concentrations in ppm under various combinations of control strategies.

Table 22. YEARS OF ATTAINMENT OF THE CO STANDARD FOR DIFFERENT CONTROL STRATEGIES.

Control Strategy	Year of Attainment of the CO Standard	Maintained through year
Base Case (Transportation System Improvements, Improved Mass Transit and Regional Development Planning)	1990	1996
Base Case + Inspection/Maintenance	1988	2000+
Base Case + Periodic Maintenance	1985	2000+
Base Case + Carpooling	1990	1998
Base Case + Inspection/Maintenance + Carpooling	1987	2000+
Base Case + Periodic Maintenance + Carpooling	1984	2000+

A SUMMARY OF CO AIR QUALITY

The main findings of this chapter are presented in this section.

The APRAC-II model, after it was calibrated for the Phoenix area, was used to determine spatial variations in CO concentrations, to pinpoint hot spots and to calculate the highest 8-hour CO concentration for the base year emissions scenario. It was also used to simulate CO air quality for the 1985 and 1995 scenarios with only the basic control strategies of traffic system improvements, improved mass transit and regional development planning, as well as with additional control strategies of inspection/maintenance and carpooling.

From results of these simulations, it was evident that one could relate peak 8-hour CO readings to emissions. This is not surprising since CO is an inert pollutant and therefore, given the same meteorology, χ/Q (where χ is the concentration and Q the emissions) must be conserved provided the relative distribution of Q is the same. Values of χ/Q for different years of interest, 1980, 1985, 1990, 1995 and 2000 were developed and peak 8-hour CO readings were computed for different scenarios of emissions.

No attainment of the standard was predicted for the 1980 case with any proposed control strategy, or combination of control strategies, in effect. For the 1985 case, the addition to the base case of periodic maintenance or periodic maintenance and carpooling would be the only controls that would bring the peak CO reading to less than the standard. With only the three basic control strategies of traffic system improvements, improved mass transit and regional development planning, it was determined that the 8-hour CO standard would be attained for the 1990 scenario, and maintained for 1995 but not for the 2000 scenario. The addition of carpooling alone would give the same result. If any one of inspection/maintenance, periodic maintenance, inspection/maintenance and carpooling, or periodic maintenance and carpooling, were implemented with the base case, the CO standard would be maintained for both the 1995 and 2000 scenarios.

Emission reductions obtained from the implementation of dealers emissions control maintenance guarantee, clean air rebate, vapor recovery, bicycle systems, and work and driving schedule shifts were determined to lead to a negligible improvement in CO air quality.

VIII. PHOTOCHEMICAL OXIDANT AIR QUALITY PROJECTIONS

Photochemical oxidant is a secondary pollutant. In other words, it is not emitted by any source. Rather, it is formed when hydrocarbons and nitrogen oxides in the ambient air are irradiated by sunlight. Therefore, to reduce the concentration of oxidant would require controlling the emissions of oxidant precursors.

The Environmental Protection Agency has developed an approach whereby one can approximate the reduction in non-methane hydrocarbon emissions (NMHC) required to attain the 1-hour oxidant standard of 160 $\mu g/m^3$. This approach is known as the Appendix J method (Appendix J. 40CFR, Part 51) and is used here to evaluate the effectiveness of proposed control strategies in the maintenance of oxidant air quality in Phoenix.

The second highest oxidant reading in 1975 was 259 $\mu g/m^3$. Based on Figure 26, the essence of the Appendix J method, the reduction in NMHC emissions required to maintain the oxidant standard is 38%. The total NMHC emissions in Phoenix in 1975 were 221.7 tons/day (see Chapter IV). This implies that the maximum allowable NMHC emissions for maintenance of the oxidant standard is 137.5 tons/day. A linear rollback method of determining maximum allowable emissions would lead to approximately the same result.

Non-methane HC emissions in the Phoenix Metropolitan Area at five year intervals from 1985 to 2000 with only the strategies that are in the MAG regional plan, (traffic system improvements, improved mass transit and regional development planning) as well as with additional proposed strategies were presented in Chapter VI.

Figure 27 shows these emission levels and compares them with the maximum allowable emission level of 137.5 tons/day. Without additional control, the air quality standard would be attained by 1986 and maintained thereafter. Implementation of any of the control strategies shown in the figure would expedite the attainment and maintenance of the oxidant standard. The addition of carpooling or vapor recovery would result in attainment in 1985. The addition of inspection/maintenance or periodic maintenance would lead to attainment in 1982.

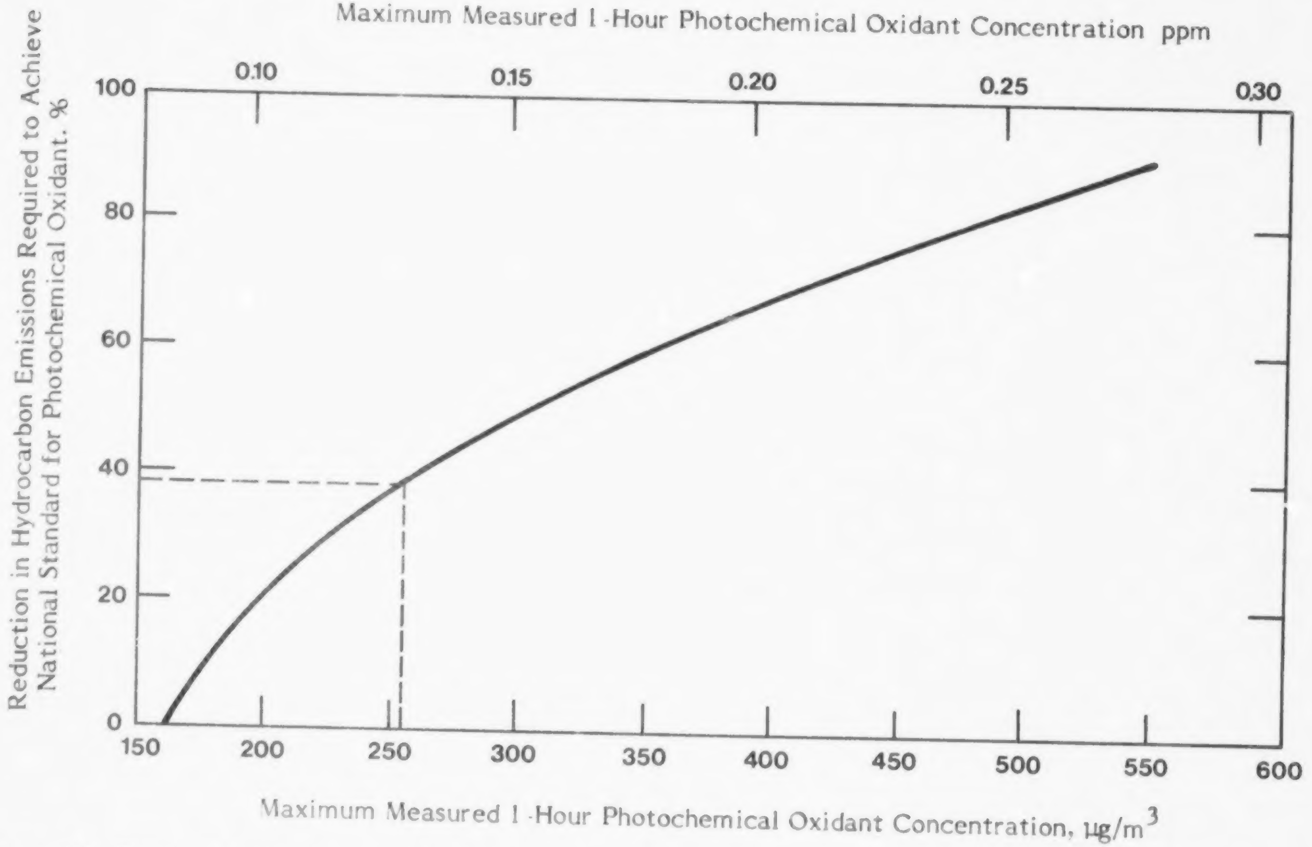

Figure 26. Required hydrocarbon emission control as a function of photochemical oxidant concentration. Maximum allowable NMHC emissions = 137.5 tons/day (Reference: Air Quality Criteria for Nitrogen Oxides AP-84 EPA. Washington, D.C., January 1971.)

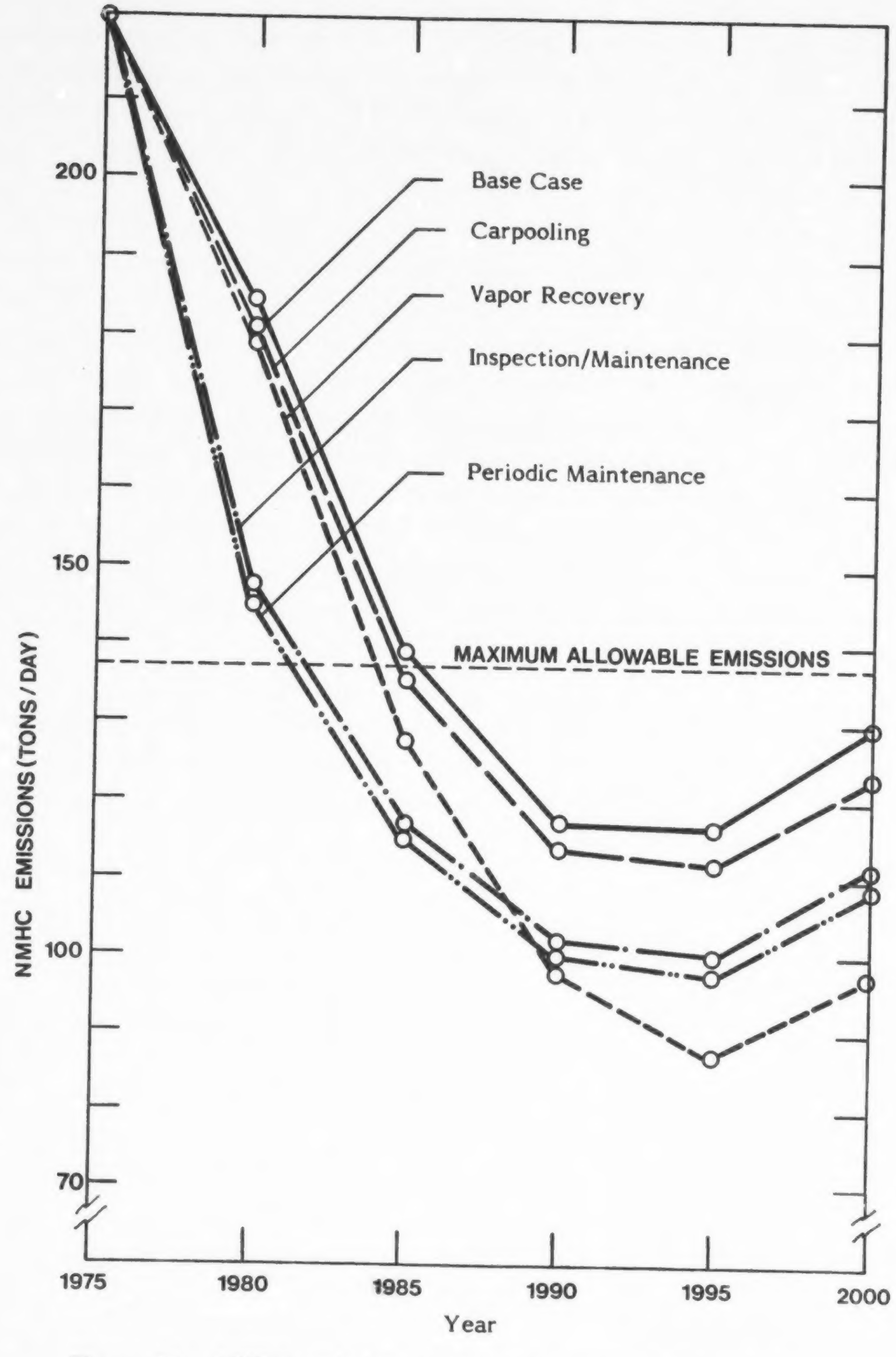

Figure 27. NMHC emissions (tons/day) under various control strategies (base case incorporates strategies in regional plan only).

Other control strategies proposed, i.e., dealer emissions control maintenance guarantee, clean air rebate, bicycle systems and work and driving schedule shifts, do not have any significant effect on the NMHC emissions inventory. Then implementation would, therefore, not result in an noticeable improvement in oxidant air quality.

The effect of implementing more than one additional control strategy is illustrated in Figures 28 through 31. Inspection/maintenance and periodic maintenance cannot co-exist. Therefore, there are seven combinations of different additional control strategies, namely (1) inspection/maintenance and carpooling, (2) periodic maintenance and carpooling, (3) inspection/maintenance and vapor recovery, (4) periodic maintenance and vapor recovery, (5) inspection/maintenance, carpooling and vapor recovery, (6) periodic maintenance, carpooling and vapor recovery, and (7) carpooling and vapor recovery. Combination (1) and (2) would lead to attainment of the oxidant standard in 1982; combinations (3) through (6) in 1981 and combination (7) in 1984. Inspection/maintenance or periodic maintenance are nearly interchangeable in the combinations with periodic maintenance showing only a slight advantage.

A summary of the attainment years for all proposed control strategies that result in a significant reduction in NMHC emissions is presented in Table 23. According to the Appendix J approach, the oxidant standard would be maintained from date of attainment through the year 2000.

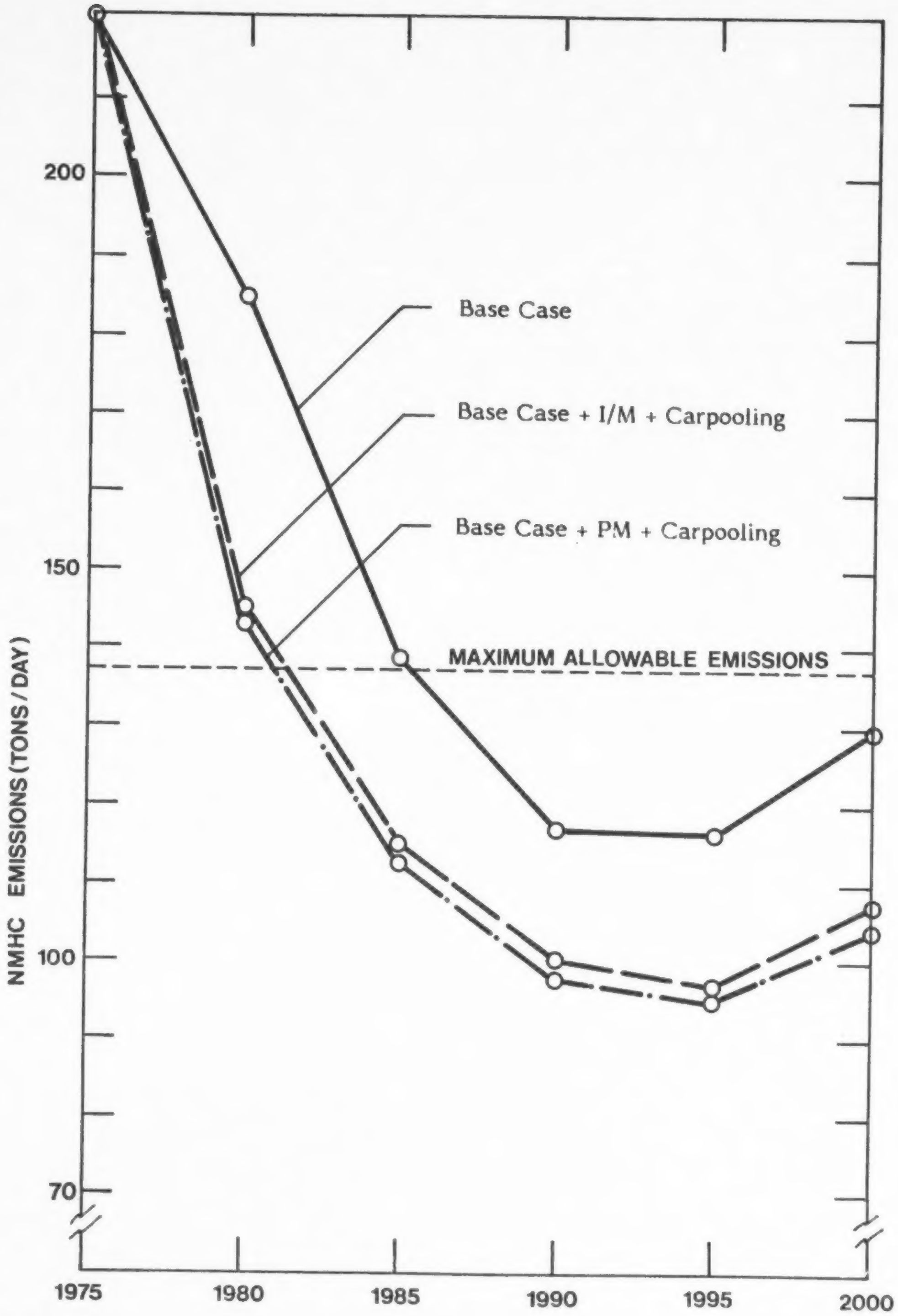

Figure 28. NMHC emissions (tons/day) under various combinations of control strategies utilizing carpooling.

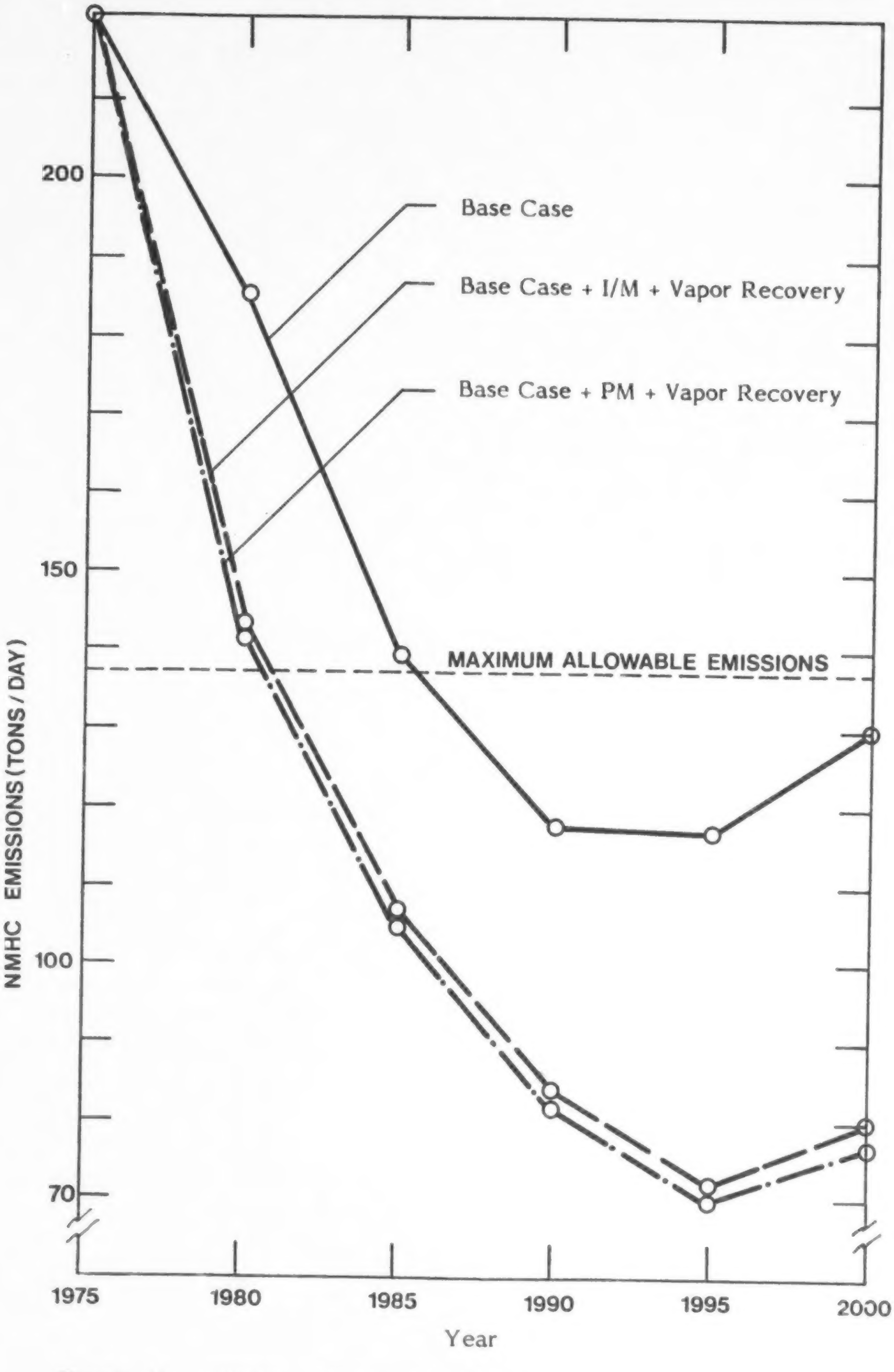

Figure 29. NMHC emissions (tons/day) under various combinations of control strategies utilizing vapor recovery.

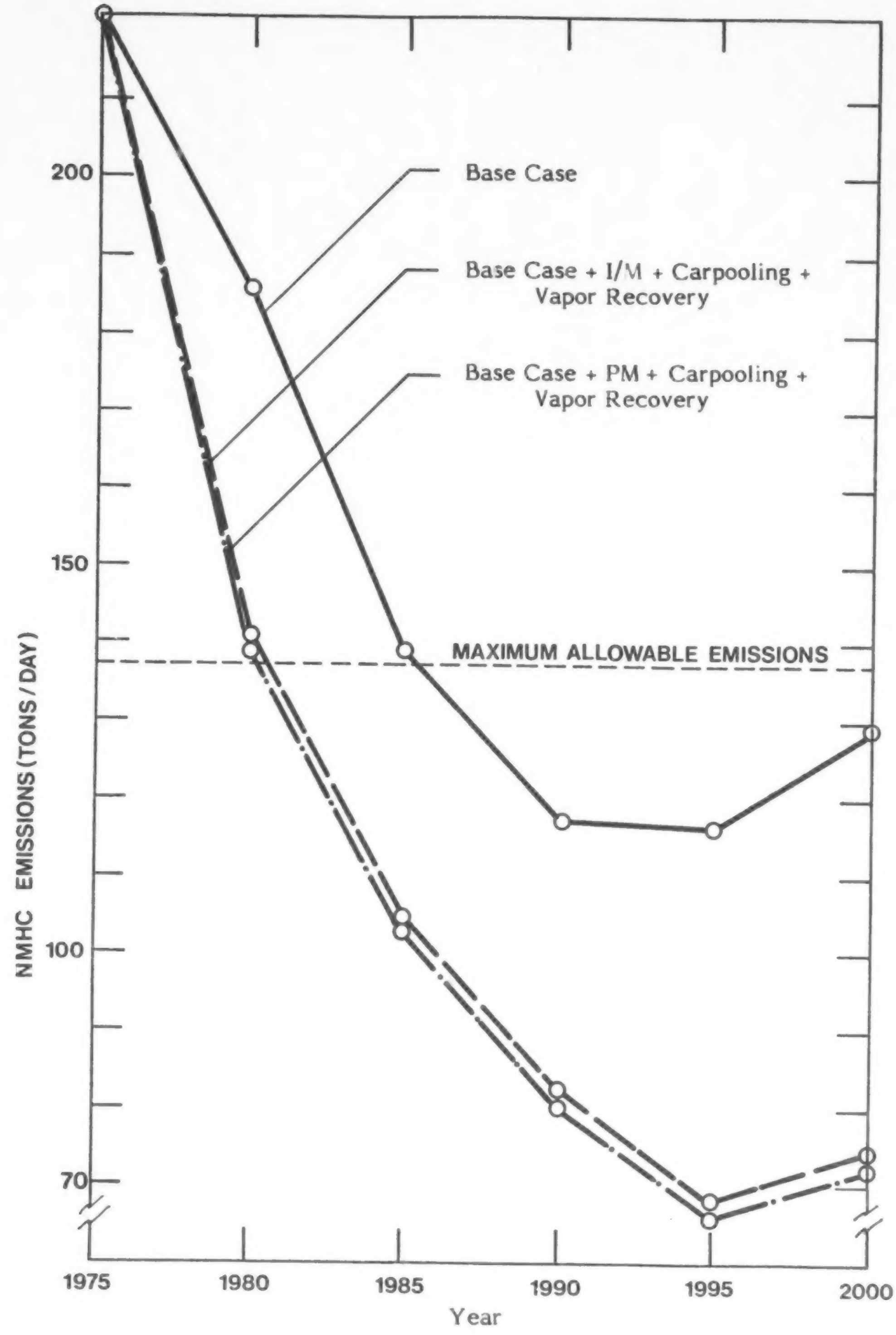

Figure 30. NMHC emissions (tons/day) under various combinations of control strategies utilizing vapor recovery and carpooling.

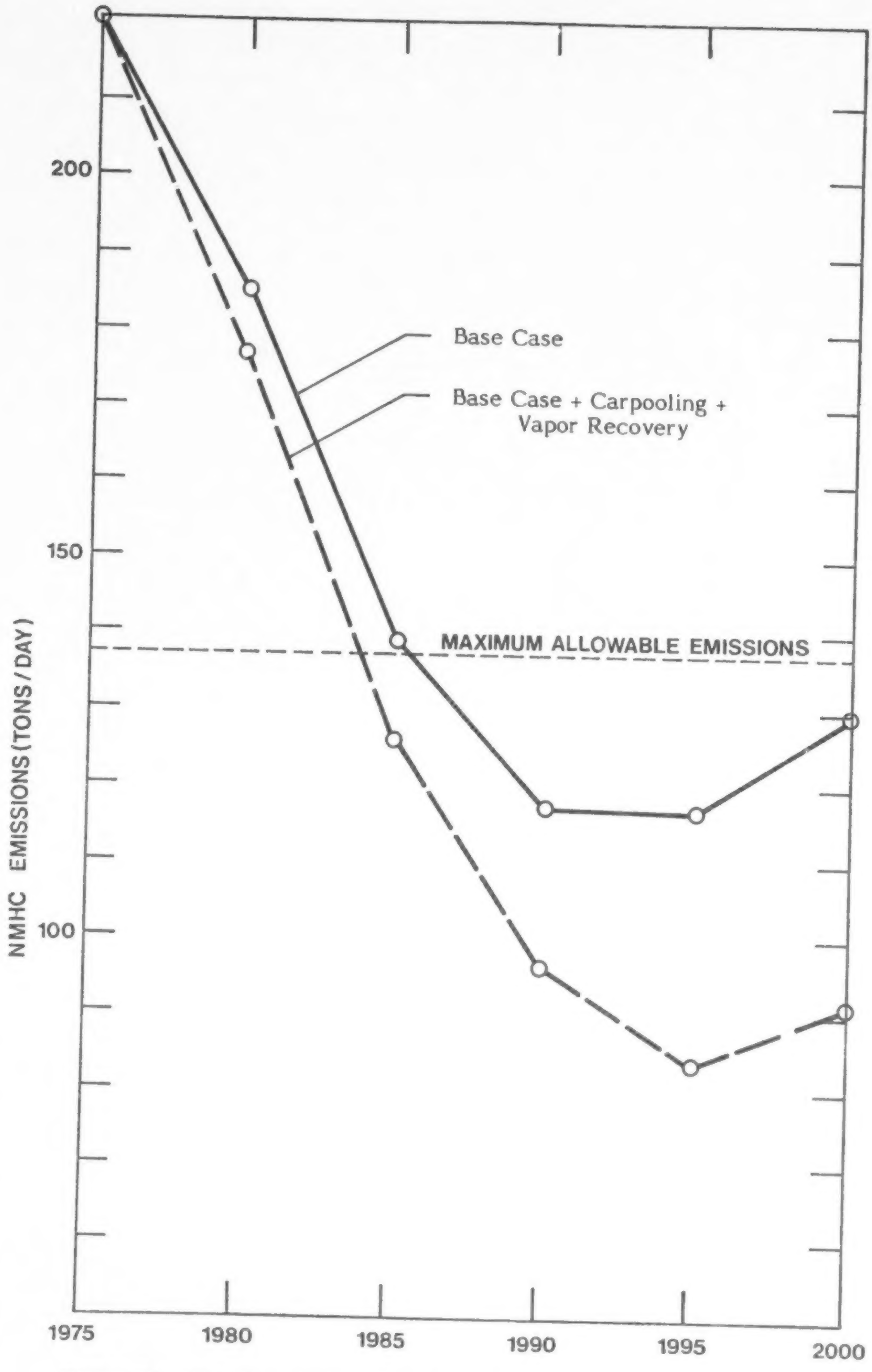

Figure 31. NMHC emissions (tons/day) for the base case and carpooling and vapor recovery in addition to base case.

Table 23. YEARS OF ATTAINMENT OF THE OXIDANT STANDARD FOR DIFFERENT CONTROL STRATEGIES.

Control Strategy	Year of Attainment of the Oxidant Standard[1]
Base Case (Traffic System Improvements, Improved Mass Transit and Regional Development Planning)	1986
Base Case + Inspection/Maintenance	1982
Base Case + Periodic Maintenance	1982
Base Case + Carpooling	1985
Base Case + Vapor Recovery	1985
Base Case + Inspection/Maintenance + Carpooling	1982
Base Case + Periodic Maintenance + Carpooling	1982
Base Case + Inspection/Maintenance + Vapor Recovery	1981
Base Case + Periodic Maintenance + Vapor Recovery	1981
Base Case + Inspection/Maintenance + Carpooling + Vapor Recovery	1981
Base Case + Periodic Maintenance + Carpooling + Vapor Recovery	1981
Base Case + Carpooling + Vapor Recovery	1984

[1] Oxidant standard will be maintained through 2000 for all control strategies.

IX. CONCLUSIONS

Maximum 8-hour CO readings were predicted for 1980, 1985, 1990, 1995 and 2000. When only the basic control strategies of traffic system improvements, improved mass transit and regional development planning were implemented, the maximum 8-hour CO readings for all but the 1990 and 1995 cases were greater than the national standard of 9 ppm. The additional control strategies that are effective in reducing CO emissions are inspection/maintenance, periodic maintenance, carpooling, inspection/maintenance and carpooling, and periodic maintenance and carpooling. The implementation of any of these additional strategies, except carpooling, would bring about the maintenance of CO standard in 2000. For the 1980 case, no attainment of the standard was predicted no matter what control strategies were implemented. For the 1985 case, the addition of periodic maintenance or periodic maintenance and carpooling would bring the peak CO reading to less than the standard.

With the three basic control strategies, the oxidant standard would be attained by 1986 and maintained through 2000. The addition of any control strategy would expedite the attainment and prolong the maintenance of the standard. No matter what strategies were implemented, the oxidant standard would not be attained before 1981.

Table 24 summarizes carbon monoxide and oxidant standard attainment years under various control strategies.

The most effective method of attaining the CO and oxidant standards would be by the implementation of periodic maintenance and carpooling, in addition to the three basic strategies. Since inspection/maintenance has already been implemented, conversion to periodic maintenance would require serious study and consideration of cost effectiveness and socio-economic impact. Although dealer emissions control maintenance guarantee and clean air rebate do not themselves contribute directly to CO or NMHC emission reductions, they provide incentive to the conduct of inspection/maintenance or periodic maintenance. Acceptability of these two strategies by the general public should be high.

Table 24. CARBON MONOXIDE AND OXIDANT ATTAINMENT AND MAINTENANCE YEARS.

CONTROL STATEGY	CO		Oxidant[1]
	Attainment Year	Maintained Through Year	Attainment Year
Base Case	1990	1996	1986
Base Case + Carpooling	1990	1998	1985
Base Case + I/M	1988	2000+	1982
Base Case + Carpooling + I/M	1987	2000+	1982
Base Case + PM	1985	2000+	1982
Base Case + Carpooling + PM	1984	2000+	1982
Base Case + I/M + Vapor Recovery	-	-	1981
Base Case + PM + Vapor Recovery	-	-	1981
Base Case + I/M + Carpooling + Vapor Recovery	-	-	1981
Base Case + PM + Carpooling + Vapor Recovery	-	-	1981
Base Case + Carpooling + Vapor Recovery	-	-	1984
Base Case + Vapor Recovery	-	-	1985

[1] Oxidant standard will be maintained through 2000 for all control strategies.

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APPENDIX A

Traffic Emissions -- Base Year (1975)
and Projections for 1985 and 1995

This appendix presents details of traffic emission computation for the years 1975, 1985, and 1995.

METHODOLOGY

Traffic data for the 1975, 1985 and 1995 systems were provided by the Transportation and Planning Office of the Maricopa Association of Governments. Population levels of 1.7 million and 2.2 million were used for projecting the 1985 and 1995 traffic systems respectively.

The volume, link length and capacity for each link in each roadway network were read off the loaded historical record of traffic assignments. This information was processed through a computer by means of AVSUP5, a computer program developed by AeroVironment to compute emissions from highway vehicles according to procedures outlined in Compilation of Air Pollutant Emission Factors, AP42 (U.S. EPA, 1976).

The averaged daily volume on each link was divided into hourly volumes according to the percent ADT by facility type presented in Table A-1. These percentages were derived from actual counts taken during January, 1974, at a freeway and arterial station in Phoenix. Traffic counts during other periods show very similar percentages.

The hourly volume was further stratified into five types of vehicles by facility type (Table A-2). These five types of vehicles are light-duty gasoline-powered passenger cars and trucks, light-duty diesel-powered vehicles, and heavy-duty gasoline-powered and diesel-powered trucks. As in Supplement 5 to AP42, light-duty vehicles are vehicles rated at less than 8500 pounds gross vehicle weight while heavy-duty vehicles are vehicles rated at more than 8500 pounds gross vehicle weight. The stratification between light-and heavy-duty vehicles by hour was obtained from actual class counts on a Phoenix freeway and arterial in April 1972. Subdivisions into different classes of light- and heavy-duty vehicles was obtained from 1976 vehicle registration records in Maricopa County. Furthermore, based on registration records, the motorcycle population was assumed to be equivalent to 4.11% of the total number of other vehicles. Also, the ratio of motorcycle VMT to light duty vehicle VMT is 1/6.66 based on AP-42 (U.S. EPA, 1976).

Table A-1. PERCENT ADT BY FACILITY TYPE FOR PHOENIX (1974).

Hour	Freeways	Arterials
0	1.3	1.6
1	.8	.8
2	.5	.3
3	.5	.2
4	.6	.2
5	1.3	.6
6	4.5	3.1
7	9.4	8.1
8	7.7	6.5
9	5.3	4.8
10	4.9	4.9
11	4.9	5.5
12	4.8	6.1
13	5.0	6.0
14	5.7	6.0
15	7.1	7.5
16	9.4	8.8
17	8.5	8.2
18	5.0	5.4
19	3.7	3.9
20	2.5	3.1
21	2.4	3.4
22	2.3	2.7
23	1.9	2.3

Table A-2. LIGHT AND HEAVY-DUTY VEHICLE STRATIFICATION BY HOUR AND FACILITY TYPE.

	Light Duty								Heavy Duty			
	LD Vehicle				LD Truck							
	Gas		Diesel		Gas		Diesel		Gas		Diesel	
Hour	Fwy.	Art.	Fwy.	Art.	Fwy.	Art.	Fwy.	Art.	Fwy.	Art.	Fwy.	Art.
0	75.24	77.64	.03	.03	18.72	19.32	0.01	0.01	4.74	2.37	1.26	0.63
1	70.43	76.04	.03	.03	17.53	18.92	0.01	0.01	9.48	3.95	2.52	1.05
2	66.44	73.63	.02	.03	16.53	18.33	0.01	0.01	13.43	6.32	3.57	1.68
3	66.44	72.03	.02	.03	16.53	17.93	0.01	0.01	13.43	7.90	3.57	2.10
4	68.03	73.63	.03	.03	16.93	18.33	0.01	0.01	11.85	6.32	3.15	1.68
5	72.03	76.04	.03	.03	17.93	18.92	0.01	0.01	7.90	3.95	2.10	1.05
6	73.64	78.44	.03	.03	18.33	19.52	0.01	0.01	6.32	1.58	1.68	0.42
7	73.64	77.64	.03	.03	18.33	19.32	0.01	0.01	6.32	2.37	1.68	0.63
8	68.83	72.83	.03	.03	17.13	18.13	0.01	0.01	11.06	7.11	2.94	1.89
9	68.83	72.83	.03	.03	17.13	18.13	0.01	0.01	11.06	7.11	2.94	1.89
10	69.63	71.23	.03	.03	17.33	17.73	0.01	0.01	10.27	8.69	2.73	2.31
11	70.43	72.03	.03	.03	17.53	17.93	0.01	0.01	9.48	7.90	2.52	2.10
12	72.03	72.03	.03	.03	17.93	17.93	0.01	0.01	7.90	7.90	2.10	2.10
13	71.23	72.03	.03	.03	17.73	17.93	0.01	0.01	8.69	7.90	2.31	2.10
14	72.03	72.83	.03	.03	17.93	18.13	0.01	0.01	7.90	7.11	2.10	1.89
15	74.43	74.43	.03	.03	18.53	18.53	0.01	0.01	5.53	5.53	1.47	1.47
16	76.84	76.84	.03	.03	19.12	19.12	0.01	0.01	3.16	3.16	0.84	0.84
17	78.44	77.64	.03	.03	19.52	19.32	0.01	0.01	1.58	2.37	0.42	0.63
18	77.64	76.84	.03	.03	19.32	19.12	0.01	0.01	2.37	3.16	0.63	0.84
19	76.84	76.04	.03	.03	19.12	18.92	0.01	0.01	3.16	3.95	0.84	1.05
20	77.64	76.84	.03	.03	19.32	19.12	0.01	0.01	2.37	5.16	0.63	0.84
21	76.84	75.24	.03	.03	19.12	18.72	0.01	0.01	3.16	4.74	0.84	1.26
22	77.64	77.64	.03	.03	19.32	19.32	0.01	0.01	2.37	2.37	0.63	0.63
23	76.84	78.44	.03	.03	19.12	19.52	0.01	0.01	3.16	1.58	0.84	0.42

The speed on each link was assumed to be a function of the ratio of volume to capacity. The variation of average speed with volume to capacity ratios by functional class by area type is presented in Table A-3, which was obtained from Special Area Analysis, a document prepared by the Federal Highway Administration (1973). However, to reflect reality, a speed limit of 55 mph instead of 65 mph was assumed for freeways in the suburbs.

The emission due to primary traffic along each link was then computed as a sum of emissions contributed by each type of vehicle. For each vehicle type, emission was calculated as follows: $E = eV$ where E is the total emission, e is the emission factor and V is the vehicle-miles traveled, which is the product of the vehicle volume and the link length. The emissions for a system was then calculated as the sum of emissions for each link.

It was assumed that in addition to emissions from traffic on the roadway network, there were emissions from secondary traffic which consisted of light-duty vehicles with an amount equivalent to 14% of the primary traffic and a speed of 20 mph.

Table A-4 presents motor vehicle emissions of CO and NMHC by vehicle type for 1975, 1985 and 1995. In calculating these emissions, emission factors for the different types of vehicles were computed according to the procedures in Supplement 5 to AP42 as follows. In determining the methane (non-reactive) content of automobile emissions, the 6-class reactivity scheme of Trijonis and Arledge (1975) was used. This classification scheme is presented in Table A-5.

LIGHT-DUTY, GASOLINE-POWERED VEHICLES

The calculation of composite emission factors for light-duty vehicles is given by

$$e_{npstwx} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}\, z_{ipt}\, r_{iptwx}$$

where: e_{npstwx} = Composite emission factor in grams per mile (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x).

Table A-3. VARIATION OF AVERAGE SPEED WITH VOLUME TO CAPACITY RATIOS (V/C) BY FUNCTIONAL CLASS BY AREA TYPE.

	Average Speed (mph)				
	Freeways		Arterials [1]		
V/C	CBD/CC [2]	Sub [3]	CBD	CC	Sub
0	50.0	55.0	21.8	29.8	32.2
.1	48.0	52.5	21.3	29.5	32.0
.2	46.0	50.0	20.8	29.2	31.8
.3	44.0	48.0	20.3	28.8	31.6
.4	42.0	46.0	19.8	28.5	31.4
.5	40.0	44.0	19.3	28.2	31.2
.6	38.0	41.0	18.8	27.8	31.0
.7	36.0	39.0	18.3	27.5	30.8
.8	34.0	36.0	17.8	27.2	30.6
.9	32.0	33.0	16.4	21.1	22.8
1.0	30.0	30.0	15.0	15.0	15.0
1.1	27.0	27.0	13.0	13.0	13.0
1.2	24.0	24.0	11.0	11.0	11.0
1.3	21.0	21.0	9.0	9.0	9.0
1.4	18.0	18.0	7.0	7.0	7.0
1.5	15.0	15.0	5.0	5.0	5.0
1.6	15.0	15.0	3.0	3.0	3.0

[1] Parkways and expressways are categorized as arterials for speed determinations.

[2] CBD: Central Business District.
CC: Central City.

[3] Sub: Suburban.

Table A-4. REVISED EMISSION INVENTORIES FOR 1975, 1985 AND 1995.

Emission Sources	1975		1985		1995	
	CO tons/day	NMHC tons/day	CO tons/day	NMHC tons/day	CO tons/day	NMHC tons/day
Primary Traffic						
Light Duty Autos	607.1	80.0	116.3	32.8	65.4	21.9
Light Duty Trucks	182.3	30.6	67.1	15.1	57.2	11.1
Heavy Duty Gas Trucks	141.7	19.1	123.7	11.4	155.4	12.7
Light Duty Diesel Trucks	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Heavy Duty Diesel Trucks	4.0	0.7	5.3	1.1	7.2	1.5
Motorcycles	3.3	0.9	4.2	0.9	1.6	0.5
Subtotal	938.3	131.4	316.6	61.2	286.9	47.7
Secondary Traffic	148.4	20.3	47.6	9.2	31.7	6.5
TOTAL	1086.7	151.7	364.2	70.4	318.6	54.1

Table A-5. DISTRIBUTION (IN %) OF ORGANIC COMPOUNDS IN A 6-CLASS REACTIVITY SCHEME.*

Source Category	Mole (%)					
	Class 0 (CH_4)	Class I	Class II	Class III	Class IV	Class V
Mobile Sources						
Light Duty Gasoline Powered Vehicles						
Exhaust Emissions	10	18	0	30	19	23
Evaporative Emissions	0	5	0	58	21	16
Heavy Duty Gasoline Powered Vehicles						
Exhaust Emissions	10	18	0	30	19	23
Evaporative Emissions	0	5	0	58	21	16
Other Gasoline Powered Equipment						
Exhaust Emissions	10	18	0	30	19	23
Evaporative Emissions	0	5	0	58	21	16
Diesel Powered Vehicles	11	2	0	24	16	57

Source: Trijonis and Arledge (1975).

* For this study, classes I through V are assumed reactive

c_{ipn} = Emission factor for the i^{th} model year light-duty vehicles during calendar year (n) and for pollutant (p).

m_{in} = The fraction of annual travel by the i^{th} model year light-duty vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year light-duty vehicles for pollutant (p), and average speed (s). This variable applies only to CO, HC, and NO_x.

z_{ipt} = The temperature correction for the i^{th} model year light-duty vehicles for pollutant (p) and ambient temperature (t)

r_{iptwx} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty vehicles for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x).

The variable c_{ipn} is summarized in Table A-6. The input m_{in} is presented in Table A-7. The speed correction factors are presented in Tables A-8 and A-9. The temperature correction and hot/cold vehicle operation correction factors are given in Table A-10. The 1975 Federal Test Procedure average values of 20% cold operation, 27% hot start-up condition and 53% hot stabilized condition were assumed, since no other information was available.

In addition to exhaust emission factors, the calculation of hydrocarbon emissions from gasoline motor vehicles involves evaporative and crankcase hydrocarbon emission factors. Composite crankcase emissions were determined using:

$$f_n = \sum_{i=n-12}^{n} h_i \, m_{in}$$

where: f_n = the composite crankcase hydrocarbon emission factor for calendar year (n)

Table A-6. CARBON MONOXIDE AND HYDROCARBON EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES FOR CALENDAR YEARS 1975, 1985 AND 1995.

	Light Duty Gasoline Powered Vehicles FTP Exhaust Emission Rates (g/mile)					
Pollutant	CO			HC		
Calendar Year Model Year	1975	1985	1995	1975	1985	1995
1963	96.0			9.0		
1964	96.0			9.0		
1965	96.0			9.0		
1966	96.0			9.0		
1967	96.0			9.0		
1968	73.6			8.0		
1969	71.4			6.3		
1970	61.0			6.3		
1971	58.5			5.1		
1972	43.0			4.1		
1973	41.0	57.0		3.8	6.2	
1974	39.0	57.0		3.5	6.2	
1975	9.0	18.0		1.0	3.0	
1976		17.1			2.8	
1977		16.2			2.6	
1978		4.8			0.7	
1979		4.5			0.6	
1980		4.2			0.5	
1981		3.9			0.5	
1982		3.6			0.4	
1983		3.4	5.6		0.4	0.8
1984		3.1	5.6		0.3	0.8
1985		2.8	5.6		0.3	0.8
1986			5.3			0.8
1987			5.0			0.7
1988			4.8			0.7
1989			4.5			0.6
1990			4.2			0.5
1991			3.9			0.5
1992			3.6			0.4
1993			3.4			0.4
1994			3.1			0.3
1995			2.8			0.3

Table A-7. FRACTION OF ANNUAL LIGHT-DUTY GASOLINE POWERED VEHICLE TRAVEL BY MODEL YEAR.

Age Years	Fraction of Total Vehicles in Use (a)	Average Annual Miles Driven (b)	a x b	Fraction of Annual Travel $(m=\frac{(axb)}{\Sigma(axb)})$
1	.066	15,900	1,049	.095
2	.089	15,000	1,335	.121
3	.111	14,000	1,554	.141
4	.105	13,100	1,376	.125
5	.084	12,200	1,025	.093
6	.084	11,300	949	.086
7	.085	10,300	876	.079
8	.071	9,400	667	.060
9	.062	8,500	527	.048
10	.059	7,600	448	.041
11	.052	6,700	348	.032
12	.038	6,700	255	.023
≥ 13	.094	6,700	630	.057

Table A-8. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR LIGHT-DUTY GASOLINE POWERED VEHICLES AND TRUCKS.[1]

Location	Model Year	$v = e^{(A + BS + CS^2)}$					
		Hydrocarbons			Carbon Monoxide		
		A	B	C	A	B	C
Low Altitude	1957-1967	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}
	1968	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}
	1969	1.005	-6.27×10^{-2}	5.80×10^{-4}	1.259	-7.72×10^{-2}	6.60×10^{-4}
	1970	0.901	-5.70×10^{-2}	5.59×10^{-4}	1.267	-7.72×10^{-2}	6.40×10^{-4}
	Post-1970	0.943	-5.92×10^{-2}	5.67×10^{-4}	1.241	-7.52×10^{-2}	6.09×10^{-4}

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[1] Equations should not be extended beyond the range of the data (15 to 45 mph). For speed correction factors at low speeds (5 and 10 mph) see Table A-9.

Table A-9. LOW AVERAGE SPEED CORRECTION FACTORS FOR LIGHT-DUTY GASOLINE POWERED VEHICLES AND TRUCKS.

Location	Model Year	Carbon Monoxide		Hydrocarbons	
		5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low Altitude	1957-1967	2.72	1.57	2.50	1.45
	1968	3.06	1.75	2.96	1.66
	1969	3.57	1.86	2.95	1.65
	1970	3.60	1.88	2.51	1.51
	Post-1970	4.15	2.23	2.75	1.63

Table A-10. LIGHT-DUTY, GASOLINE-POWERED VEHICLE AND TRUCK TEMPERATURE CORRECTION FACTORS AND HOT/COLD VEHICLE OPERATION CORRECTION FACTORS FOR FTP EMISSION FACTORS.

Pollutant and Controls	Temperature Correction Factor	Hot/Cold Vehicle Operation Correction Factors[3]	
		g(t)	f(t)
Carbon monoxide			
Non-catalyst[1]	$-0.0127t + 1.95$	-	$0.0045t + 0.02$
Catalyst[2]	$-0.0743t + 6.58$	$e^{0.035t - 5.24}$	$e^{0.036t - 4.14}$
Hydrocarbons			
Non-catalyst[1]	$-0.0113t + 1.81$	-	$0.0079t + 0.03$
Catalyst[2]	$-0.0304t + 3.25$	$0.0018t + 0.0095$	$0.0050t - 0.0409$

[1] Model years prior to 1975. In addition, one-third of the 1975-1977 light-duty trucks are assumed non-catalyst.

[2] All 1975-2000 light-duty vehicles and two-thirds of the 1975-1977 light-duty trucks.

[3] $r_{iptw} = \frac{w + (100-w)f(t)}{20 + 80\,f(t)}$ Pre-1975 model years

$r_{iptwx} = \frac{w + x\,f(t) + (100-w-x)\,g(t)}{20 + 27\,f(t) + 53\,g(t)}$ Post-1974 model years

h_i = The crankcase emission factor for the i^{th} model year

m_{in} = The weighted annual travel of the i^{th} model year during calendar year (n)

Crankcase hydrocarbon emission factors by model year are summarized in Table A-11.

There are two sources of evaporative hydrocarbon emissions from light-duty vehicles: the fuel tank and the carburetor system. Diurnal changes in ambient temperature result in expansion of the air-fuel mixture in a partially filled fuel tank. As a result, gasoline vapor is expelled to the atmosphere. Running losses from the fuel tank occur as the fuel is heated by the road surface during driving, and hot soak losses from the carburetor system occur after engine shutdown at the end of a trip. Carburetor system losses occur from such locations as the carburetor vents, the float bowl, and the gaps around the throttle and choke shafts. Because evaporative emissions are a function of the diurnal variation in ambient temperature and the number of trips per day, emissions are best calculated in terms of evaporative emissions per day per vehicle. Emissions per day can be converted to emissions per mile (if necessary) by dividing the emissions per day by an average daily miles per vehicle value. This value is likely to vary from location to location, however, The composite evaporative hydrocarbon emission factor is given by:

$$e_n = \sum_{i=n-12}^{n} (g_i + k_i d)(m_{in})$$

where: e_n = The composite evaporative hydrocarbon emission factor for calendar year (n) in lbs/day (g/day)

g_i = The diurnal evaporative hydrocarbon emission factor for model year (i) in lbs/day (g/day)

k_i = The hot soak evaporative emission factor in lbs/trip (g/trip) for the i^{th} model year

Table A-11. CRANKCASE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT-DUTY GASOLINE POWERED VEHICLES.

Model Year	Hydrocarbons	
	g/mi	g/km
Low Altitude		
Pre-1963	4.1	2.5
1963 through 1967	0.8	0.5
Post-1967	0.0	0.0

d = The number of daily trips per vehicle (a nationwide average of 3.3 trips/vehicle/day was used)

m_{in} = The weighted annual travel of the i^{th} model year during calendar year (n)

The variables g_i and K_i are presented in Table A-12 by model year.

LIGHT-DUTY, GASOLINE-POWERED TRUCKS

The composite emission factor for light-duty trucks is given by:

$$e_{npstwx} = \sum_{i=n-12}^{n} c_{ipn} m_{in} v_{ips} z_{ipt} r_{iptwx}$$

where: e_{npstwx} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

c_{ipn} = The 1975 Federal Test Procedure mean emission factor for the i^{th} model year light-duty trucks during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the i^{th} model year light-duty trucks during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year light-duty trucks for pollutant (p) and average speed (s)

Table A-12. EVAPORATIVE HYDROCARBON EMISSIONS BY MODEL YEAR FOR LIGHT-DUTY GASOLINE-POWERED VEHICLES.

Location and Model Year	By Source		Composite		
	Diurnal g/day	Hot soak g/trip	g/day	g/mi	g/km
Low Altitude					
Pre-1970	26.0	14.7	74.5	2.53	1.57
1970	26.0	14.7	74.5	2.53	1.57
1971	16.3	10.9	52.3	1.78	1.11
1972-1979	12.1	12.0	51.7	1.76	1.09
Post-1979	-	-	-	0.5	0.31

z_{ipt} = The temperature correction for the i^{th} model year light-duty trucks for pollutant (p) and ambient temperature (t)

r_{iptwx} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty trucks for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

Emission factors for light-duty trucks are summarized in Table A-13. Values for m_{in} are given in Table A-14. v_{ips}, z_{ipt}, and r_{iptwx} are the same for this class as for light-duty vehicles (see Tables A-8, A-9, and A-10).

In addition to exhaust emission factors, evaporative crankcase hydrocarbon emissions for light-duty trucks were determined using:

$$f_n = \sum_{i=n-12}^{n} h_i m_{in}$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table A-15. The crankcase and evaporative emissions reported in the table are added together to arrive at this variable.

m_{in} = The weighted annual travel of the i^{th} model year vehicle during calendar year (n)

Table A-13. CARBON MONOXIDE AND HYDROCARBONS EXHAUST EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS FOR CALENDAR YEARS 1975, 1985 AND 1995.

	Light Duty Gasoline Powered Trucks FTP Exhaust Emission Rates					
Pollutant	CO			HC		
Calendar Yr Model Year	1975	1985	1995	1975	1985	1995
1963	125.0			17.0		
1964	125.0			17.0		
1965	125.0			17.0		
1966	125.0			17.0		
1967	125.0			17.0		
1968	77.0			9.5		
1969	74.8			7.1		
1970	61.0			6.6		
1971	61.0			5.7		
1972	49.4			4.6		
1973	47.2	64.8		4.4	7.6	
1974	45.0	64.8		4.0	7.6	
1975	27.0	42.0		2.7	5.7	
1976		40.5			5.4	
1977		39.0			5.1	
1978		16.8			2.4	
1979		15.8			2.2	
1980		14.8			2.0	
1981		13.8			1.8	
1982		12.8			1.6	
1983		11.8	19.8		1.4	3.0
1984		10.8	19.8		1.2	3.0
1985		9.8	19.8		1.0	3.0
1986			18.8			2.8
1987			17.8			2.6
1988			16.8			2.4
1989			15.8			2.2
1990			14.8			2.0
1991			13.8			1.8
1992			12.8			1.6
1993			11.8			1.4
1994			10.8			1.2
1995			9.8			1.0

Table A-14. FRACTION OF ANNUAL LIGHT-DUTY GASOLINE-POWERED TRUCK TRAVEL BY MODEL YEAR.

Age, Years	Fraction of Total Vehicles in Use (a)	Average Annual Miles Driven (b)	a x b	Fraction of Annual Travel ($m = \frac{(axb)}{\Sigma(axb)}$)
1	.063	15,900	1,002	.092
2	.096	15,000	1,440	.132
3	.122	14,000	1,708	.157
4	.106	13,100	1,389	.128
5	.070	12,200	854	.078
6	.072	11,300	814	.075
7	.071	10,300	731	.067
8	.052	9,400	489	.045
9	.047	8,500	400	.037
10	.046	7,600	350	.032
11	.042	6,700	281	.026
12	.039	6,700	261	.024
$\geq$ 13	.174	6,700	1,166	.107

Table A-15. CRANKCASE AND EVAPORATIVE HYDROCARBONS EMISSION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED TRUCKS.

Location	Model Years	Crankcase Emissions		Evaporative Emissions	
		g/km	g/mi	g/km	g/mi
Low Altitude	Pre-1963	2.9	4.6	2.2	3.6
	1963-1967	1.5	2.4	2.2	3.6
	1968-1970	0.0	0.0	2.2	3.6
	1971	0.0	0.0	1.9	3.1
	1972-1979	0.0	0.0	1.9	3.1
	Post-1979	0.0	0.0	0.3	0.5

LIGHT-DUTY, DIESEL-POWERED VEHICLES

Carbon monoxide, hydrocarbons, and nitrogen oxides emission factors for the light-duty, diesel-powered vehicle are shown in Table A-16. These factors are based on tests of several Mercedes 220D automobiles using a slightly modified version of the Federal light-duty vehicle test procedure. Emissions from light-duty diesel vehicles during a calendar year (n) and for a pollutant (p) were calculated using:

$$e_{np} = \sum_{i=n-12}^{n} c_{ipn} m_{in}$$

where: e_{np} = Composite emission factor in grams per vehicle mile for calendar year (n) and pollutant (p)

c_{ipn} = The 1975 Federal test procedure emission rate for pollutant (p) in grams/mile for the i^{th} model year at calendar year (n) (Table A-16).

m_{in} = The fraction of total light-duty diesel vehicle miles driven by the i^{th} model year diesel light-duty vehicles (Table A-17).

HEAVY-DUTY, GASOLINE-POWERED VEHICLES

The composite exhaust emission factor was calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn} m_{in} v_{ips}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

Table A-16. EMISSION FACTORS FOR LIGHT-DUTY, DIESEL-POWERED VEHICLES.

	Light-Duty Diesel Powered Vehicles FTP Exhaust Emission Rates					
Pollutant	CO			HC		
Calendar Yr. Model Year	1975	1985	1995	1975	1985	1995
1963	1.7			0.5		
1964	1.7			0.5		
1965	1.7			0.5		
1966	1.7			0.5		
1967	1.7			0.5		
1968	1.7			0.5		
1969	1.7			0.5		
1970	1.7			0.5		
1971	1.7			0.5		
1972	1.7			0.5		
1973	1.7	1.7		0.5	0.5	
1974	1.7	1.7		0.5	0.5	
1975	1.7	1.7		0.5	0.5	
1976		1.7			0.5	
1977		1.7			0.5	
1978		1.7			0.5	
1979		1.7			0.5	
1980		1.7			0.5	
1981		1.7			0.5	
1982		1.7			0.5	
1983		1.7	1.7		0.5	0.5
1984		1.7	1.7		0.5	0.5
1985		1.7	1.7		0.5	0.5
1986			1.7			0.5
1987			1.7			0.5
1988			1.7			0.5
1989			1.7			0.5
1990			1.7			0.5
1991			1.7			0.5
1992			1.7			0.5
1993			1.7			0.5
1994			1.7			0.5
1995			1.7			0.5

Table A-17. FRACTION OF ANNUAL LIGHT-DUTY, DIESEL-POWERED TRAVEL BY MODEL YEAR.

Age, Years	Fraction of total Vehicles in Use (a)	Average Annual Miles Driven (b)	a x b	Fraction of Annual Travel ($m=\frac{(axb)}{\Sigma(axb)}$)
1	.138	15,900	2,194.2	.201
2	.084	15,000	1,260.0	.115
3	.040	14,000	560.0	.051
4	.074	13,100	969.4	.089
5	.051	12,200	622.2	.057
6	.064	11,300	723.2	.066
7	.111	10,300	1,143.3	.105
8	.131	9,400	1,231.4	.113
9	.081	8,500	688.5	.063
10	.034	7,600	258.4	.024
11	.064	6,700	428.8	.039
12	.024	6,700	160.8	.015
$\geq$ 13	.104	6,700	696.8	.064

c_{ipn} = The test procedure emission factor for pollutant (p) in g/mi (g/km) for the i^{th} model year in calendar year (n)

m_{in} = The weighted annual travel of the i^{th} model year vehicles during calendar year (n). The determination of this variable involves the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed (s)

The projected test procedure emission factors (c_{ipn}) are summarized in Table A-18. These projected factors are based on the San Antonio Road Route test and assume 100 percent warmed-up vehicle operation at an average speed of approximately 18 mph. Table A-19 contains fraction of annual heavy-duty gasoline powered vehicle travel by model year. Speed correction factor data are contained in Tables A-20 and A-21.

In addition to exhaust emission factors, the calculation of evaporative and crankcase hydrocarbon emissions were determined using:

$$f_n = \sum_{i=n-12}^{n} h_i \, m_{in}$$

where: f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase hydrocarbon emission rate for the i^{th} model year. Emission factors for this source are reported in Table A-22.

m_{in} = The weighted annual travel for the i^{th} model year vehicle during calendar year (n)

Table A-18. CARBON MONOXIDE AND HYDROCARBON EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES.

Pollutant	Heavy Duty Gasoline Powered Vehicles FTP Exhaust Emission Rates					
	CO			HC		
Calendar Yr. Model Year	1975	1985	1995	1975	1985	1995
1963	238.0			35.4		
1964	238.0			35.4		
1965	238.0			35.4		
1966	238.0			35.4		
1967	238.0			35.4		
1968	238.0			35.4		
1969	238.0			35.4		
1970	188.0			14.1		
1971	188.0			14.0		
1972	188.0			13.9		
1973	188.0	188.0		13.8	14.4	
1974	168.0	176.0		13.2	14.0	
1975	167.0	176.0		13.1	14.0	
1976		176.0			14.0	
1977		175.0			13.9	
1978		124.0			6.3	
1979		123.0			6.2	
1980		122.0			6.2	
1981		121.0			6.2	
1982		120.0			6.1	
1983		119.0	126.0		6.1	6.3
1984		118.0	126.0		6.1	6.3
1985		117.0	126.0		6.0	6.2
1986			126.0			6.2
1987			125.0			6.2
1988			124.0			6.2
1989			123.0			6.2
1990			122.0			6.2
1991			121.0			6.1
1992			120.0			6.1
1993			119.0			6.1
1994			118.0			6.0
1995			117.0			6.0

Table A-19. FRACTION OF ANNUAL HEAVY-DUTY, GASOLINE-POWERED VEHICLE TRAVEL BY MODEL YEAR.

Age, Years	Fraction of Total Vehicles in Use (a)	Average Annual Miles Driven (b)	a x b	Fraction of Annual Travel ($m = \frac{(axb)}{\Sigma(axb)}$)
1	.059	19,000	1,121.0	.090
2	.097	18,000	1,746.0	.140
3	.110	17,000	1,870.0	.149
4	.148	16,000	2,368.0	.189
5	.063	14,000	882.0	.071
6	.069	12,000	828.0	.066
7	.071	10,000	710.0	.057
8	.043	9,500	408.5	.033
9	.042	9,000	378.0	.030
10	.043	8,500	365.5	.029
11	.033	8,000	264.0	.021
12	.031	7,500	232.5	.019
≥ 13	.191	7,000	1,337.0	.106

Table A-20. COEFFICIENTS FOR SPEED CORRECTION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES.[1]

		$v = e^{(A + BS + CS^2)}$					
	Model	Hydrocarbons			Carbon Monoxide		
Location	Year	A	B	C	A	B	C
Low Altitude	Pre-1970	0.953	-6.00×10^{-2}	5.81×10^{-4}	0.967	-6.07×10^{-2}	5.78×10^{-4}
	Post-1969	1.070	-6.63×10^{-2}	5.98×10^{-4}	1.047	-6.52×10^{-2}	6.01×10^{-4}

[1] Equations should not be extended beyond the range of the data (15 to 45 mph). For speed correction factors at low speeds (5 and 10 mph) see Table A-21.

Table A-21. LOW AVERAGE SPEED CORRECTION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES.

		Carbon Monoxide		Hydrocarbons	
Location	Model Year	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)	5 mi/hr (8 km/hr)	10 mi/hr (16 km/hr)
Low Altitude	Pre-1970	2.72	1.57	2.50	1.45
	Post-1969	3.06	1.75	2.96	1.66

Table A-22. CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR HEAVY-DUTY, GASOLINE-POWERED VEHICLES.

Location	Model Years	Crankcase Emissions		Evaporative Emissions	
		g/mi	g/km	g/mi	g/km
Low Altitude	Pre-1968	5.7	3.5	5.8	3.6
	1968-1978	0.0	0.0	5.8	3.6
	Post-1978	0.0	0.0	2.9	1.8

HEAVY-DUTY, DIESEL-POWERED VEHICLES

Emissions from heavy-duty, diesel-powered vehicles during a calendar year (n) and for a pollutant (p) were calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

c_{ipn} = The emission rate in g/mi (g/km) for the i^{th} model year vehicles in calendar year (n) over a transient urban driving schedule with average speed of approximately 18 mi/hr

m_{in} = The fraction of total heavy-duty diesel miles (km) driven by the i^{th} model year vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year heavy-duty diesel vehicles for pollutant (p) and average speed (s)

Values for c_{ipn} are given in Table A-23; values for m_{in} are in Table A-24. The speed correction factor (v_{ips}) was computed using data in Table A-25.

MOTORCYCLES

The composite exhaust emission factor was calculated using:

$$e_{nps} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}$$

where: e_{nps} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), and average speed (s)

Table A-23. CARBON MONOXIDE, HYDROCARBON EXHAUST EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED VEHICLES BY CALENDAR YEAR.

	Heavy-Duty Diesel Powered Vehicles FTP Exhaust Emission Rates					
Pollutant	CO			HC		
Calendar Yr. Model Year	1975	1985	1995	1975	1985	1995
1963	28.7			4.6		
1964	28.7			4.6		
1965	28.7			4.6		
1966	28.7			4.6		
1967	28.7			4.6		
1968	28.7			4.6		
1969	28.7			4.6		
1970	28.7			4.6		
1971	28.7			4.6		
1972	28.7			4.6		
1973	28.7	28.7		4.6	4.6	
1974	28.7	28.7		4.6	4.6	
1975	28.7	28.7		4.6	4.6	
1976		28.7			4.6	
1977		28.7			4.6	
1978		28.7			4.6	
1979		28.7			4.6	
1980		28.7			4.6	
1981		28.7			4.6	
1982		28.7			4.6	
1983		28.7	28.7		4.6	4.6
1984		28.7	28.7		4.6	4.6
1985		28.7	28.7		4.6	4.6
1986			28.7			4.6
1987			28.7			4.6
1988			28.7			4.6
1989			28.7			4.6
1990			28.7			4.6
1991			28.7			4.6
1992			28.7			4.6
1993			28.7			4.6
1994			28.7			4.6
1995			28.7			4.6

TABLE A-24. FRACTION OF ANNUAL HEAVY-DUTY DIESEL-POWERED VEHICLE TRAVEL BY MODEL YEAR.

Age, Years	Fraction of Total Vehicles in Use (a)	Average Annual Miles Driven (b)	a x b	Fraction of Annual Travel $(m = \frac{(axb)}{\Sigma(axb)})$
1	.058	70,000	4,060	.076
2	.105	70,000	7,350	.137
3	.153	70,000	10,710	.200
4	.115	70,000	8,050	.151
5	.095	62,000	5,890	.110
6	.074	50,000	3,700	.069
7	.075	46,000	3,450	.065
8	.054	43,000	2,322	.043
9	.057	42,000	2,394	.045
10	.046	30,000	1,380	.026
11	.030	25,000	750	.014
12	.030	25,000	750	.014
$\geq$ 13	.107	25,000	2,675	.050

Table A-25. EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED VEHICLES UNDER DIFFERENT OPERATING CONDITIONS (g/min).

Pollutant	Operating Mode		
	Idle	Urban (18 mi/hr; 29 km/hr)	Over-the-road (60 mi/hr; 97 km/hr)
Carbon Monoxide	0.64	8.61	5.40
Hydrocarbons	0.32	1.38	2.25
Nitrogen Oxides (NO_x as NO_2)	1.03	6.27	28.3

For average speeds less than 18 mi/hr (29 km/hr), the correction factor is:

$$v = \frac{\text{Urban} + \left(\frac{18}{S} - 1\right) \text{Idle}}{\text{Urban}}$$

Where: S is the average speed of interest (in mi/hr), and the urban and idle values (in g/min) are obtained from Table A-25. For average speeds above 18 mi/hr (29 km/hr), the correction factor is:

$$v = \frac{\frac{18}{42S}\left[(60-S)\ \text{Urban} + (S-18)\ \text{Over the Road}\right]}{\text{Urban}}$$

Where: S is the average speed (in mi/hr) of interest. Urban and over-the-road values (in g/min) are obtained from Table A-25. Emission factors for heavy-duty diesel vehicles assume all operation to be under warmed-up vehicle conditions. Temperature correction factors, therefore, are not included because ambient temperature has minimal effects on warmed-up operation.

c_{ipn} = The test procedure emission factor for pollutant (p) in g/mi (g/km) for the i^{th} model year in calendar year (n)

m_{in} = The weighted annual travel of the i^{th} model year vehicles during calendar year (n). The determination of this variable involved the use of the vehicle year distribution.

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed (s)

The emission factor results of the Federal Test Procedure (c_{ipn}) as modified for motorcycles are summarized in Table A-26. Table A-27 contains fraction of annual travel by model year. Because there are no speed correction factor data for motorcycles, the variable v_{ips} was assumed to equal one. The emission factor for crankcase and evaporative hydrocarbons is presented in Table A-28.

Table A-26. CARBON MONOXIDE AND HYDROCARBON EXHAUST EMISSION FACTORS FOR MOTORCYCLES FOR CALENDAR YEAR 1975, 1985 AND 1995.

	Motorcycles FTP Exhaust Emission Rates					
Pollutant	CO			HC		
Calendar Yr. Model Year	1975	1985	1995	1975	1985	1995
1963	30.6			8.1		
1964	30.6			8.1		
1965	30.6			8.1		
1966	30.6			8.1		
1967	30.6			8.1		
1968	30.6			8.1		
1969	30.6			8.1		
1970	30.6			8.1		
1971	30.6			8.1		
1972	30.6			8.1		
1973	30.6	30.6		8.1	8.1	
1974	30.6	30.6		8.1	8.1	
1975	30.6	30.6		8.1	8.1	
1976		30.6			8.1	
1977		30.6			8.1	
1978		30.6			8.1	
1979		30.6			8.0	
1980		30.6			7.5	
1981		30.6			7.0	
1982		30.6			6.5	
1983		30.6	30.6		6.0	8.1
1984		29.4	30.6		5.5	8.1
1985		3.4	30.6		0.4	8.1
1986			30.6			8.1
1987			30.6			8.1
1988			30.6			8.1
1989			30.6			8.0
1990			5.1			0.8
1991			4.8			0.7
1992			4.4			0.6
1993			4.1			0.6
1994			3.7			0.5
1995			3.4			0.4

Table A-27. FRACTION OF ANNUAL MOTORCYCLE TRAVEL BY MODEL YEAR.

Age, Years	Fraction of Total Vehicles in Use (a)	Average Annual Miles Driven (b)	a x b	Fraction of Annual Travel ($m= \frac{(axb)}{\Sigma(axb)}$)
1	.112	2,500	280.0	.173
2	.157	2,100	329.7	.203
3	.171	1,800	307.8	.190
4	.146	1,600	233.6	.144
5	.123	1,400	172.2	.106
6	.087	1,200	104.4	.064
7	.051	1,100	56.1	.035
8	.042	1,000	42.0	.026
9	.029	950	29.6	.017
10	.022	900	19.8	.012
11	.016	850	13.6	.008
12	.008	800	6.4	.004
≥ 13	.037	800	29.6	.018

Table A-28. CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSION FACTORS FOR MOTORCYCLES.

	Emissions[a]			
	2-Stroke Engine		4-Stroke Engine	
Pollutant	g/mi	g/km	g/mi	g/km
Hydrocarbons				
Crankcase[b]	--	--	0.60	0.37
Evaporative[c]	0.36	0.22	0.36	0.22

[a] The motorcycle population was assumed to be 60 percent 4-stroke and 40 percent 2-stroke when computing emission rates.

[b] Most 2-stroke engines use crankcase induction and produce no crankcase losses.

[c] Evaporative emissions were calculated assuming that carburetor losses were negligible. Diurnal breathing of the fuel tank (a function of fuel vapor pressure, vapor space in the tank, and diurnal temperature variation) was assumed to account for all the evaporative losses associated with motorcycles. The value presented is based on average vapor pressure, vapor space, and temperature variation.

REFERENCES

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APPENDIX B

Traffic Emission Projections to 1980, 1990 and 2000

This appendix gives details of traffic emission projections for the years 1980, 1990, and 2000 given emissions for the years 1975, 1985, and 1995 (see Sections IV and VI and Appendix A of this report). Vehicle miles travelled (VMT) and emission factors for each vehicle class for the years 1980, 1990, and 2000 were obtained. Emissions were then computed using the equation:

$$E = \sum_i (VMT)_i \cdot (EF)_i$$

where: E = Total traffic emissions

$(VMT)_i$ = Total vehicle miles traveled for vehicle class i

$(EF)_i$ = Emission factor for vehicle class i at the average speed.

VMT for each vehicle class and both facility types (freeway and arterial) for 1975, 1985 and 1995 were obtained from traffic data supplied by the Transportation and Planning Office of the Maricopa Association of Governments (MAG-TPO). Linear interpolation and extrapolation were applied to this data to get VMT for 1980, 1990, and 2000. These VMT's are shown graphically in Figure B-1.

To compute emission factors for the years 1980, 1990, and 2000, average speeds for the years 1975, 1985, and 1995 were extracted for each vehicle class and facility type by relating emissions to VMT. These speeds were then interpolated for 1980, 1990, and 2000 and are shown in Table B-1. Emission factors were computed using AP-42 (EPA, 1976) using these speeds and are presented on Tables B-2 and B-3. Secondary traffic was again assumed to have 14% of primary traffic VMT with an average speed of 20 mph and the following vehicle mix: 80.04% light-duty gas vehicles, 19.92% light-duty trucks, and 0.04% light-duty diesel vehicles. Emissions for 1980, 1990, and 2000 were then obtained by using the emission factors and VMT for those years. Projected traffic emissions for 1980, 1990, and 2000 by vehicle type are presented in Table B-4. Figure B-2 presents traffic emission trends through 2000.

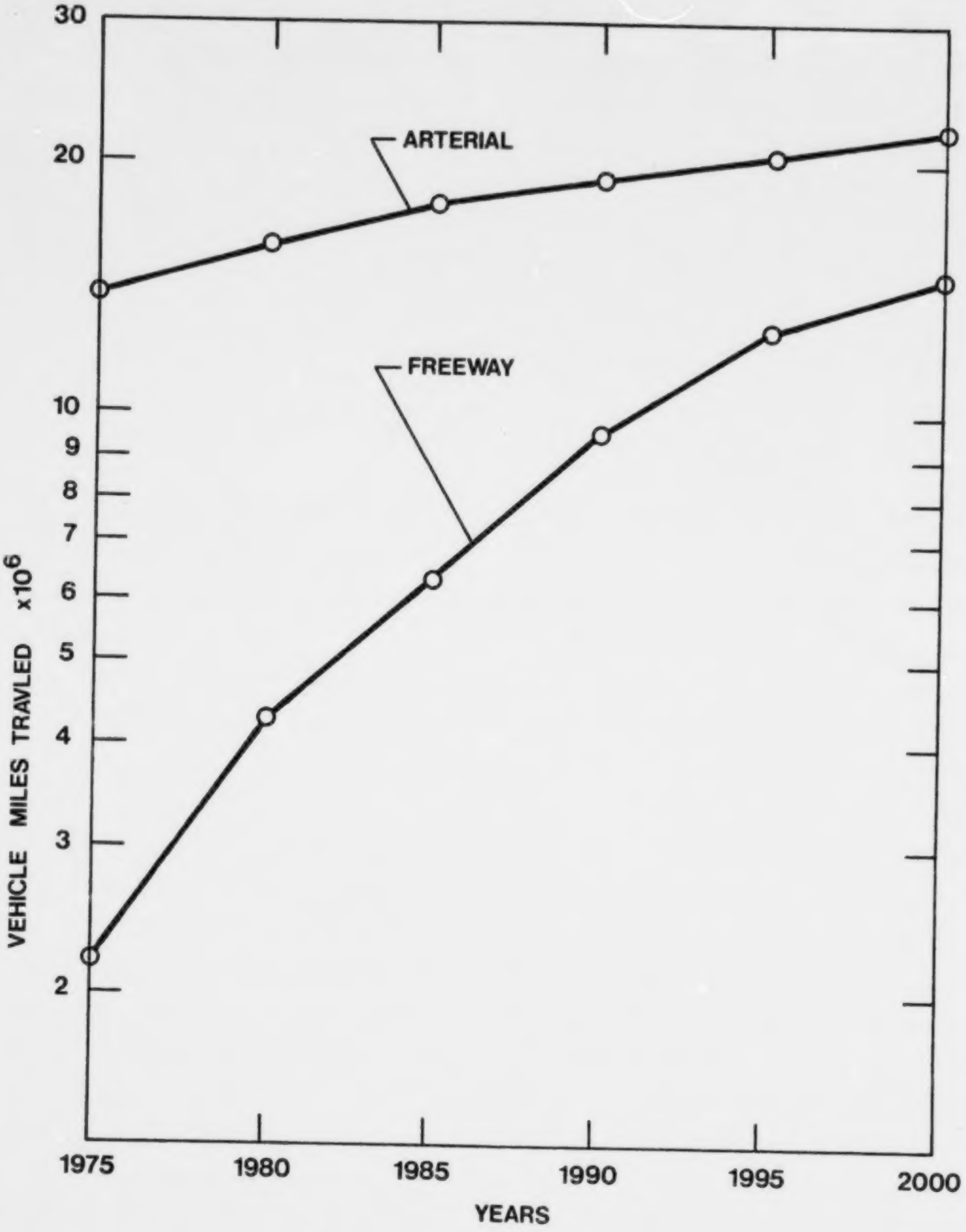

Figure B-1.Projected vehicle miles traveled by facility type.

Table B-1. AVERAGE VEHICLE SPEEDS BY VEHICLE CLASS AND FACILITY TYPE. (mph)

Facility Type	Year	LDV[1]	LDT[2]	HDV[2]	HDD[4]
Freeway	1975	42	42	42	43
Arterial		24	24	24	26
Freeway	1980	42	41	40	41
Arterial		28	27	27	28
Freeway	1985	42	40	39	40
Arterial		32	30	29	29
Freeway	1990	42	39	38	39
Arterial		33	29	29	30
Freeway	1995	43	37	38	39
Arterial		34	29	29	30
Freeway	2000	42	39	38	39
Arterial		33	29	29	30

[1] LDV: Light-duty gasoline vehicle

[2] LDT: Light-duty gasoline truck

[3] HDV: Heavy duty gasoline vehicle

[4] HDD: Heavy duty diesel vehicle

Table B-2. CO EMISSION FACTORS DERIVED FROM AVERAGE SPEEDS. (g/mi)

Year	Vehicle Class / Func. Class	LDV	LDT	HDV	LDD[1]	HDD	MC[2]
1980	Secondary[3]	27.65	39.54	--	1.7	--	--
	Arterial	19.40	29.01	122.96	1.7	16.90	29.91
	Freeway	12.63	18.74	89.60	1.7	10.00	29.91
1990	Secondary	4.85	14.42	--	1.7	--	--
	Arterial	2.78	9.58	86.28	1.7	15.50	7.26
	Freeway	2.13	6.83	68.97	1.7	10.91	7.26
2000	Secondary	4.85	14.42	--	1.7	--	--
	Arterial	2.68	9.58	86.28	1.7	15.50	7.26
	Freeway	2.08	7.25	68.97	1.7	10.91	7.26

[1] LDD: Light duty diesel vehicle

[2] MC: Motorcycle

[3] Secondary traffic was assumed to have the following vehicle mix: 80.04% LDV, 19.92% LDT, and 0.04% LDD

Table B-3. NMHC EMISSION FACTORS DERIVED FROM AVERAGE SPEEDS. (g/mi)

Year	Vehicle Class Funct. Class	LDV	LDT	HDV	LDD	HDD	MC
1980	Secondary	4.34	6.95	--	.41	--	-
	Arterial	3.74	6.10	13.81	.41	3.06	6.49
	Freeway	3.24	5.26	11.28	.41	2.44	6.49
1990	Secondary	1.08	2.50	--	.41	--	--
	Arterial	.92	2.09	6.35	.41	2.97	2.04
	Freeway	.88	1.86	5.69	.41	2.52	2.04
2000	Secondary	.98	2.16	--	.41	--	--
	Arterial	.82	1.75	6.69	.41	2.97	2.04
	Freeway	.78	1.55	5.97	.41	2.52	2.04

Table B-4. PROJECTED TRAFFIC EMISSIONS BY VEHICLE TYPE.
(tons/day)

Category	1980		1990		2000	
	CO	NMHC	CO	NMHC	CO	NMHC
1. Primary Traffic						
a. Light duty gas vehicle	293.6	59.4	59.8	21.1	74.4	24.6
b. Light duty gas truck	109.1	22.0	50.3	11.7	65.6	12.7
c. Heavy duty gas truck	132.1	15.2	135.2	10.4	177.9	14.5
d. Light duty diesel vehicle	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
e. Heavy duty diesel vehicle	4.6	0.9	6.2	1.2	8.1	1.7
f. Motorcycle	4.0	0.9	1.4	0.4	1.8	0.5
Subtotal	543.4	98.4	252.9	44.8	327.8	54.0
2. Secondary traffic	91.7	14.9	29.6	6.0	38.9	7.0
Total traffic	635.1	114.3	282.5	50.8	366.7	61.0

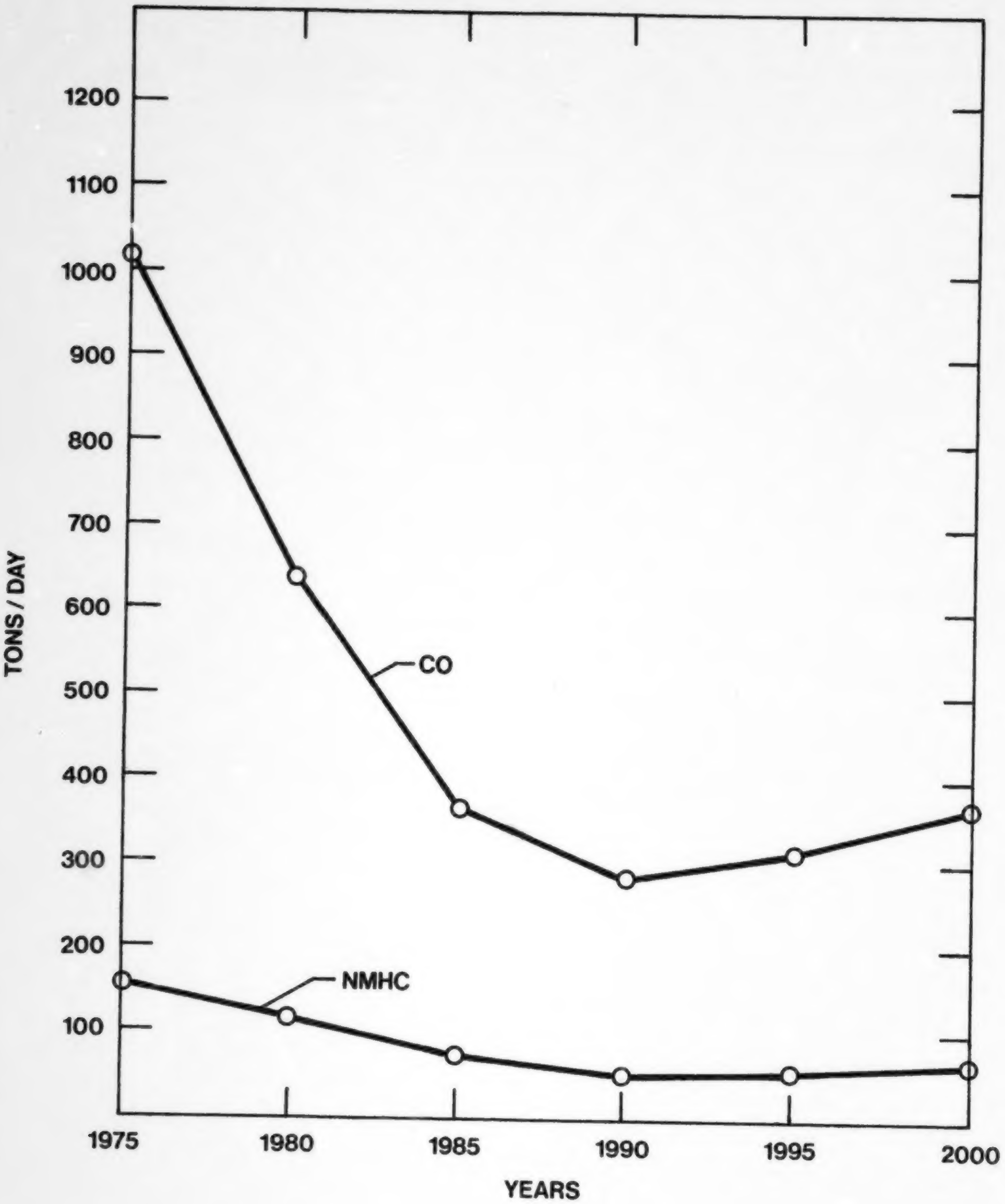

Figure B-2.Traffic emissions trend through 2000.

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APPENDIX C

Non-Traffic Emissions
Base Year (1975)

This appendix presents details of non-traffic emission computation for the base year (1975). It consists of the pertinent parts of "Emission Inventory Report for the Phoenix Study Area," (Pacific Environmental Services, 1976).

A summary table is presented in Table C-1.

I. BACKGROUND

The baseline document for the emissions inventory is the National Emissions Data System (NEDS) Summary, run date of January 27, 1976. (Ref. 1) Despite the date of the Summary, it actually represents emissions data from the year 1972. Since the year of record for the emissions inventory is 1975, the first step required was to update the status of entries in various categories of emission sources.

Maricopa Association of Governments (MAG) loaned PES the master copy of the recently updated 1975 land use map. PES had the map photographed in color, and had 20" x 24" color prints made for gridding and determination of land uses over the entire study area.

II. EMISSION SOURCES

ELIMINATION OF SOURCES

As a result of ordinances passed in 1971, there is no longer any open burning in the Phoenix area. Incineration is conducted within the commercial and industrial areas, but there is no residential incineration. The 1975 emission summary now reflects the deletion of emissions resulting from the above action.

1972-1975 GROWTH

Conversations with Mr. Charles Mann, National Aerometric Data Bank, Research Triangle Park, North Carolina and with Mr. Witherspoon of the Maricopa County Department of Public Health also confirmed the fact that the January 27, 1976 NEDS Summary reflects emissions data from calendar 1972. Maricopa County indicated that

Table C-1. SUMMARY TABLE.
1975 TOTAL EMISSIONS FOR PHOENIX AREA
(short tons/year)

Category	CO	THC	NMHC
1. Point Sources	265	4,925	4,916
2. Area Sources			
a. Residential	233	93	0
b. Comm./Inst.	385	166	96
c. Industrial	1,745	767	502
d. Miscellaneous	361	18,133	18,133
3. Airports	9,901	1,076	1,073
4. Railroads	1,112	804	788
TOTAL	14,002	25,964	25,508

updated emissions information for 1973, 1974, or 1975 had not been and would not be made avialable at this time but that reestimates of these emissions based on population increases from 1972 to 1975 would be realistic.

PES has therefore made reestimates of some of the categories of emissions in the January 1976 NEDS Summary as follows:

1. According to DES (Department of Economic Security – official estimator for Arizona) (Reference 2, page 78), the population of Maricopa County for 1972 was 1,069,750 and for 1975 was 1,230,000 or a gain of 15 percent for those three years. Population within the planning area is approximately 98 percent of Maricopa County. To obtain area emissions for the study area for 1975, the NEDS Summary totals were increased by 14.7 percent (15 x .98) for the following emission categories:

    a. Fuel combustion

        1. Residential
        2. Industrial
        3. Commercial/Institutional

    b. On-site incineration

        1. Commercial/Institutional
        2. Industrial

    c. Solvent evaporation loss

2. Electrical power generation

    a. Comparison of power generated in 1972 and 1975. FPC form Is for four major electric generating plants in Phoenix indicated that the total power generated in 1975 = 1.925 x 10^6 MWHR and total power generated in 1972 = 4.090 x 10^6 MWHR for a net decrease of 2.165 x 10^6 MWHR or 53 percent.

This decrease of electrical power generated in the study area is caused primarily by the increasing trend to have base power load supplied by the generating stations at Navajo, Cholla, and Santan,with Ocotillo, Agua Fria and Kyrene supplying peak loads. This downward trend is expected to continue over the next twenty years.

b. Fuel for power generation. Another feature which effected the change in emissions for power generation between 1972 and 1975 was the percentage of fuel oil and natural gas used for each of those two years. Data obtained from FPC, and verified by both the Arizona Public Service and Salt River Project plants indicated that the use of natural gas had decreased by a factor of almost six, while the use of fuel oil had increased by a factor of more than four.

3. Miscellaneous area-wide sources

a. Gasoline handling evaporation losses. Normally the 1972 emissions for this category would have been increased by the same percentage as the population growth to obtain 1975 emissions. In view of the energy crises of 1973 and 1974 however, the consumption in 1975 was estimated at 104 percent of the 1972 figure.

b. Solvent evaporation and structural fires. 1972 emissions were increased by 14.7 percent (population increase). Emissions caused by frost control measures were deleted since the majority of those would be emitted outside the study area.

4. Aircraft emissions

Baseline emissions from NEDS, 1976, were not employed since more accurate and precise information was obtained from other sources.

a. Military aircraft. Luke Air Force Base on the Western extremity of the study area and Williams Air Force Base in the Southeast corner are the only two airports accommodating significant military aircraft operations in this area, although some military aircraft operations are included under Sky Harbor International Airport operations. Information on landing and takeoff cycles, touchdowns, type and number of aircraft, airport areas, hours and days of operation and emission factors were obtained from References 3 through 6.

b. Commercial aircraft. All major airlines using commercial aircraft operate out of Sky Harbor International Airport. Although some data was obtained from FAA sources, the final selection of data utilized of this report was taken from References 7, 8 and 9.

c. Civil aircraft. There are eight airports (including Sky Harbor) in the study area which handle sufficient numbers of civil aircraft to be included in the report. The key reference employed was Reference 7, with supporting information obtained from References 10, 11, and 12. The mix of civil aircraft types registered at Sky Harbor Airport was obtained from Reference 7, "Final Environmental Impact Statement for Phoenix Sky Harbor International Airport Improvement Program – August 1974." This document also contained emissions per landing/takeoff cycle (LTO) and frequency of civil aircraft operations. The emissions for a composite civil aircraft were calculated as explained in Section III; that same value was applied to the known aircraft operations for 1975 at the other seven (7) civil airports. Although the exact airport land areas were available, the airport areas as read from MAG's 1975 land use map were employed in determining emissions to the appropriate grid and still maintain the integrity of the land use patterns shown on the MAG map. (See also Table C-2).

5. Railroads

The total emissions from railroads in Maricopa County were obtained from Reference 1, updated by a 4 percent growth factor for 1975 (one-half of the Arizona Statement Implementation Plan for growth of 8 percent between 1969 and 1975). Total length of rail lines in Maricopa County for Southern Pacific and Santa Fe railroads were obtained from the district traffic

Table C-2. CIVIL AIRPORT FACILITIES – PHOENIX AREA.

	1975	
Name	Aircraft Registered	Total Aircraft Movements
Chandler Municipal	54[a] 15[b]	60,000[a] * 12,000[b]
Deer Valley	325[a] 300[c]	135,000[a] 275,000[b] 166,246[c]
Falcon Field-Mesa	330[a] 222[b]	275,000[a] * 175,000[b]
Glendale Municipal	123[b]	20,000[a] * 100,000[b,d]
Phoenix-Litchfield	103[a] 94[b] 96[c]	125,000[a] 80,000[b] 122,000[c]
Scottsdale Municipal	126[a] 202[b]	60,000[a] * 150,000[b,d]
Sky Harbor (Civil Aircraft Operations Only)	600[a] 600[c]	264,000[a] 322,433[c]
Stellar City Air Park	70[b]	* 60,000[b]
TOTALS	1628[e]	1,107,679[e]

Notes:

a. FAA Reports 5010-1
b. Landrum and Brown Reports
c. Sky Harbor Airport Reports
d. Airport Manager Estimates
e. PES Estimates

* Using estimate of 844 movements per aircraft from Landrum and Brown.

Underlined figures indicate those selected by PES from sources available and used in calculations in Section III.

offices of those two railroads for both through lines and support or switching lines. U.S.G.S. maps for the Phoenix area, railroad yard maps and railroad computer readouts were employed to compute the total rail lines in each grid. Discussion with traffic control representatives from both railroads indicated that it was realistic to allocate the same emission factor for both through lines and switching lines.

6. Point sources

A total of thirty-nine (39) point sources with THC and/or CO emissions were obtained from the NEDS Point Source Listing for Arizona, by county, (NEDS FORM 4) dated November 14, 1975. (Reference 13). Despite the date of this report, the data represent 1972 emissions. In updating these emissions to 1975, four sources were deleted completely due to discontinuance of operation and four (all power plants) required complete recalculation of emissions based upon FPC and power plant reports for 1975 and using emissions factors in AP42. (Reference 14).

Emissions in kg/hr were computed for 250 days/year (except as noted for individual sources), based upon the production work schedule for 1975 obtained via telephone conversation with each soruce. Discussions with Mr. Gregg Witherspoon indicated that it would be realistic to assume no increase in process emissions between 1972 and 1975.

7. Computations for airport emissions

Emissions for THC and CO were first obtained in tons/year for the individual airport. Airport areas were read from the 1975 land use map and differed in almost each case from the total airport areas as obtained from FAA, Sky Harbor Authority or Military Base Reports.

III. STATISTICAL DATA AND COMPUTATIONS FOR PHOENIX AREA EMISSIONS INVENTORY, 1975

A. STATISTICAL DATA

		Tons/year	
		THC	CO
1. Residential			
Fuel Combustion		93	233
Area - Low Density	199.67	Low Density Factor = 1	
- High Density	13.44	High Density Factor = 4	
(Sq. Miles) TOTAL	213.11	Total Residential Equivalent Units = 253.4	
2. Commercial/Institutional			
Fuel Combustion		83	196
Incineration		83	189
TOTAL		166	385
Area = 52.95 Sq. Miles			
3. Industrial			
Fuel Combustion		25	38
Incineration		742	1707
TOTAL		767	1745
Area = 20.63 Sq. Miles			
4. Area Wide Sources (Miscellaneous)			
Gas Handling		7000	
Solvent Evaporation and Structural Fires		11133	361
TOTAL		18133	361
Area = 306.4 Sq. Miles			

	Tons/year	
	THC	CO
5. Railroads	1458	2017
Total Miles in Maricopa County = 385 miles		
(Total Miles in Phoenix Study Area = 212 Miles)		
6. Aircraft		
a. Sky Harbor Airport		
Commercial	168	404
Civil	18	1009
Military	35.3	250
TOTAL	221.3	1663
b. Civil Airports		
Chandler Municipal	.7	37.6
Deer Valley	9.2	520
Falcon Field-Mesa	9.7	548
Glendale Municipal	5.6	313
Phoenix - Litchfield	6.8	382
Scottsdale Municipal	8.3	470
Stellar City Air Park	3.3	188
c. Military Airports		
Luke AFB	360	3014
Williams AFB	451	2765

7. Airport Areas	Sq. Miles	
	1975 Land Use Map	FAA Reports 5010-1
Sky Harbor	1.883	3.125
Civil Airports	3.115	4.27

7. Airport Areas (cont'd)

Luke AFB	0.875	6.53
Williams AFB	2.406	5.78
TOTAL	8.279	19.71*

8. Total Areas

Total Areas	Sq. Miles
Residential	213.11
Commercial/Institutional	52.95
Industrial	20.63
Airports	19.71
TOTAL	306.74

B. COMPUTATIONS OF ANNUAL EMISSION FACTORS PER SQUARE MILE

Annual emission factors per sq. mile are obtained by dividing the annual emissions by the emission area in sq. miles

Category	THC	CO
Residential - Low Density	$\frac{93}{253.4}$ = 0.367	$\frac{233 \text{ tons/yr.}}{253.4 \text{ sq. miles}}$ = 0.919 tons/yr/sq. mile
Residential -- High Density	Low Residential x 4 = 1.468	= 3.676 tons/yr/sq. mile
Commercial/ Institutional	$\frac{166}{52.95}$ = 3.135	$\frac{385 \text{ tons/yr.}}{52.95 \text{ sq. miles}}$ = 7.271 tons/yr/sq. mile

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* 19.71 square miles of airport area used to compute total land use areas for miscellaneous emissions.

Industrial	$\frac{767}{20.63}$ = 37.179	$\frac{1745 \text{ tons/yr}}{20.63 \text{ sq. miles}}$ = 84.585 tons/yr/sq. mile
Miscellaneous	$\frac{18133}{306.4}$ = 59.181	$\frac{361 \text{ tons/yr}}{306.4 \text{ sq. miles}}$ = 1.178 tons/yr/sq. mile
Railroads	$\frac{1458}{385}$ = 3.787	$\frac{2017 \text{ tons/yr}}{385 \text{ miles}}$ = 5.239 tons/yr/mile

C. 1975 DISTRIBUTION OF THC INTO METHANE AND NON-METHANE PERCENTAGE (REF. 16 used for estimate of %).

	CH_4 %	NMHC %
Residential		
Fuel Combustion	100%	0%
Commercial/Institutional		
Fuel Combustion	50%	50%
Incineration	34%	66%
Industrial		
Fuel Combustion	50%	50%
Incineration	34%	66%
Area Wide Source (Miscellaneous)		
Gas Handling	--	100%
Solvent Evaporation & Structural Fires	--	100%
Railroads		
(212 out of 385 miles)	2%	98%
Aircraft		
Jet (Commercial & Military)	0%	100%
Piston (Civil Aircraft)	5%	95%
Power Plant		
Gas	100%	0%
Oil	5%	95%

D. ELECTRIC GENERATING PLANTS – PHOENIX 1972 AND 1975

Plant/Year	Net Power Generated KWHR x 10^6	Fuel Used		Emissions Tons/Yr.	
		Gas MCF x 10^3	Oil BBL x 10^3	CO	THC
Agua Fria					
1972	2272	18860	380	184	25.4
1975	1031	2806	1381	111	59.4
Crosscut					
1972	8	138	1.2	1.2	0
1975	--	--	--	--	-
Kyrene					
1972	415	4630	86	44.8	5.9
1975	164	844	231	21.7	10.1
Ocotillo					
1972	1282	12011	116.5	109	10.9
1975	626	2465	779	70	33.9
West Phoenix*					
1972	113	1376	17.7	12.8	1.4
1975	104	578	143	13.9	6.3
Totals					
1972	4090	37015	601.4	352	44
1975	1925	6693	2534	217	110

* West Phoenix Plant was closed in the mid 1960's; then reactivated in 1969 for partial operation. It has been used to supply peak load demands especially during the summer. APS spokesmen indicated this plant will have been phased out by 1995.

REFERENCES

1. National Emissions Data Systems (NEDS) Summary Report for Maricopa County, run date January 27, 1976.

2. Maricopa Association of Governments report, "An air quality evaluation of the 1980 Transportation Improvement Program and the 1995 Transportation Plan for the Phoenix region," dated May 1, 1975.

3. Luke Air Force Base, Arizona report titled, "Air installation compatible use zone," March 1976.

4. Draft environmental statement on the F-15 Beddown at Luke Air Force Base, Arizona. AF-ES-74-3D, April 1974.

5. Telephone conversations with Major Lake, Williams Air Force Base, during May and June 1976.

6. U.S.A.F. air pollutant emission factors for landing and takeoff cycles. AFWL-TR-74-303, February 1975 and advance changes thereto.

7. Final environmental impact statement for Phoenix Sky Harbor International Airport Improvement Program, August 1974.

8. City of Phoenix Aviation Department activity reports for specific months in 1974, 1975 and 1976.

9. Sky Harbor International Airport activity reports for specific periods in 1975 and 1976.

10. General aviation airport area evaluation, Phoenix, Arizona. Prepared for the City of Phoenix Aviation Department by Landrum and Brown, February 1976.

11. Site evaluation, Goodyear Airfield, Phoenix, Arizona. Prepared for the City of Phoenix Aviation Department by Landrum and Brown, September 1975.

12. FAA airport master record (form 5010) for eight municipal airports in the Phoenix area.

13. NEDS point source listing for Arizona, by County (NEDS Form 4), dated November 14, 1975.

14. U.S. Environmental Protection Agency. Compilation of air pollutant emission factors, AP-42.

15. General Research Corporation project, "Air quality impact of electric cars in Los Angeles: Appendix A – Pollutant emissions estimates and projections for the south coast air basin," August 1974.

16. Utility of reactivity criteria in organic emission control strategies for Los Angeles. Prepared by TRW for EPA research Triangle Park, North Carolina, December 1975.

17. Pacific Environmental Services, Inc. Emission Inventory Report for the Phoenix Study Area, 1975-1995. 1976.

APPENDIX D

Non-Traffic Emission Projections

This appendix gives details of non-traffic emission computations for the years 1980, 1985, 1990, 1995, and 2000.

PES (1976) presented emissions for 1995 based on a 1.9 million population level. Growth rates and emission factors were adjusted to reflect a 2.2 million population level for that year, 1.7 million in 1985, and a linear change in between. Growth rates refer to the rate of increased/decreased use of the source, while emission factors reflect the effect of emission controls and energy conservation measures which will generally be in full effect by 1995. Table D-1 presents growth rates and emission factors for all years for the various non-traffic emission sources.

For residential area sources (fuel combustion for space heating, etc.), a growth factor of 2.123 was selected for 1995 to reflect the increased residential area (Maricopa Association of Governments Composite Land Use Map for Maricopa County). The emission factor adjustment reflects such things as electronic pilot lights and increased use of solar energy. Commercial/Institutional growth rates and emission factors were selected similarly.

The industrial growth rate was again based on area usage while emission factor adjustment was used to reflect a trend toward light industry and the population increase not accounted for by area increase.

Miscellaneous emissions are of three types: gasoline handling, solvent evaporation, and structural fires. Growth rates reflect population increase while emission factors are 1 for gasoline handling and structural fires and 0.3 for solvent evaporation, reflecting the increased use of non-polluting solvents.

The growth rate for railroads was that suggested in the State of Arizona Air Pollution Control Implementation Plan (Arizona State Department of Health, 1972). Emission factor adjustments were made to reflect population increases not taken into account by these growth rates.

For power generation, no new plants were anticipated. In addition, the trend in the Phoenix area is for electric power generation to take place outside the area. Therefore, a growth factor adjustment was made to reflect this.

Table D-1. GROWTH AND EMISSION FACTORS FOR NON-TRAFFIC SOURCES

Year / Source	1980		1985		1990		1995		2000	
	G.F.[1]	E.F.[2]	G.F.	E.F.	G.F.	E.F.	G.F.	E.F.	G.F.	E.F.
Residential	1.281	0.95	1.561	0.89	1.842	0.84	2.123	0.80	2.404	0.80
Commercial/Institutional										
a) Fuel Combustion	1.213	0.98	1.426	0.95	1.639	0.90	1.851	0.85	2.064	0.85
b) Incineration	1.213	1.00	1.426	1.00	1.639	0.93	1.851	0.85	2.064	0.85
Industrial										
a) Fuel Combustion	1.503	0.90	2.005	0.80	2.508	0.83	3.009	0.85	3.512	0.90
b) Incineration	1.503	0.80	2.005	0.60	2.508	0.65	3 009	0.70	3.512	0.80
Miscellaneous										
a) Gas Handling	1.191	1.00	1.382	1.00	1.586	1.00	1.789	1.00	1.993	1.00
b) Solvent Evaporation	1.191	0.75	1.382	0.50	1.586	0.30	1.789	0.10	1.993	0.10
c) Structural Fires	1.191	1.00	1.382	1.00	1.586	1.00	1.789	1.00	1.993	1.00
Railroads	1.061	1.00	1.127	1.00	1.196	1.04	1.270	1.079	1.347	1.119
Power Generators	0.95	1.00	0.90	1.00	0.85	1.00	0.80	1.00	0.80	1.00
Other Point Sources	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[1] G.F. = Growth Factor

[2] E.F. = Emission Factor

Other point sources were assumed to remain constant.

Sky Harbor International Airport emissions in 1995 at the 1.9 million population level (PES, 1976) were adjusted to reflect the 2.2 million population level. Emissions were not much changed from the 1985 level due to a lack of LTO cycle information after 1985.

Civil aircraft emissions for 1995, population 1.9 million, were included in PES (1976). These were adjusted to reflect the 1995 2.2 million population level. 1985 emissions were scaled to reflect the 1985/1995 total aircraft operation ratio. Intermediate years were interpolated and 2000 was extrapolated.

Military aircraft operation emissions were assumed constant through 2000 based on discussions with Air Force personnel.

Table D-2 presents projected emissions for non-traffic sources broken down by source type.

Table D-2. PROJECTED NON-TRAFFIC EMISSIONS
(tons/day)

Year / Category	1980		1985		1990		1995		2000	
	CO	NMHC	CO	NMHC	CO	NMHC	CO	NMHC	CO	NMHC
Point Sources	0.67	13.49	0.66	13.46	0.64	13.47	0.61	13.43	0.61	13.44
Area Sources										
a) Residential	0.78	0	0.89	0	0.99	0	1.08	0	1.23	0
b) Comm/Inst.	1.27	0.32	1.47	0.37	1.58	0.40	1.66	0.42	1.85	0.46
c) Industrial	5.76	1.66	5.79	1.67	7.84	2.25	10.12	2.92	13.47	3.88
d) Miscellaneous	1.18	50.09	1.37	47.58	1.57	44.93	1.77	39.77	1.97	44.30
Airports	27.90	3.00	28.65	3.07	32.30	3.21	36.09	3.36	39.70	3.50
Railroads	3.23	2.29	3.43	2.43	3.79	2.68	4.18	2.96	4.59	3.25
TOTAL	40.79	70.85	42.26	68.58	48.71	66.94	55.51	62.86	63.42	68.83

REFERENCES

Arizona State Department of Health, "The State of Arizona Air Pollution Control Implementation Plan," May 1972.

Maricopa Association of Governments, Composite Land Use Map for Maricopa County,1976.

Pacific Environmental Services, Inc., "Emission Inventory Report for the Phoenix Study Area 1975-1995", August

APPENDIX E

Effect of Control Strategies

This appendix presents details of the effects of control strategies on study area emissions.

CONTROL STRATEGY EFFECTIVENESS DATA

Source: AQMA Task Force

The following maximum percent reductions in CO and HC emissions may be attributed to each of the following control strategies selected by the AQMA Task Force.

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(1) Inspection/Maintenance Program

	Decrease	
	CO	HC
All light duty vehicle emissions (including motorcycles)	22%	37%
All heavy duty vehicle emissions	11%	7%

Source: ASDH, "Transportation Control Strategies," September 1973 and recent Bureau of Vehicular Emissions Inspection revisions.

Inspection results for the first three months of the 1977 I/M program in Phoenix show a failure rate of 16.8% corresponding to these reductions.

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(2) Periodic Maintenance

	Decrease	
	CO	HC
All light and heavy duty vehicle emissions (assuming average mileage/registered vehicle in Maricopa County = 7800)	35%	34%

Source: Evaluation Report of Clean Air Research Company for California Air Resources Board - Contract #ARB-654.

(3) Vapor Recovery

	Decrease
	HC
For 1985:	
Phase I - Total Gasoline Vapor Emissions	36%
For 1995:	
Phase I and II - Total Gasoline Vapor Emissions	81%

Maricopa County has estimated that 1975 gasoline vapor emissions from gasoline stations and distribution points = 18 tons/day.

Source: Maricopa County, "An Investigation into the Feasibility of Reducing Hydrocarbon Emissions from Gasoline Evaporation Sources in Maricopa County," September 1976.

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(4) Dealer Emissions Guarantee

Supports stated effectiveness of I/M or Periodic Maintenance Program.

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(5) Clean Air Rebate

Supports stated effectiveness of I/M or Periodic Maintenance Program.

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(6) Carpooling

The 1985 and 1995 MAG assignments used to develop the AVSUP5 mobile source emissions inventories assume 1970 auto occupancy levels. Increasing car occupancy from 1.33 in 1970 to 1.4 in 1985 and 1.5 in 1995 has the following impact on mobile source emissions:

			Decrease		
			CO Running	HC Emissions	Vehicle Trips
1985	1.7M	(1.4 vs. 1.33)	5%	5%	5%
1995	2.2M	(1.5 vs. 1.33)	12%	11%	11%

Source: MAG Sketch Planning Models

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(7) Bicycle Systems

No reduction by 1985

		Decrease CO Running	Decrease HC Emissions	Decrease Vehicle Trips
1995	2.2M	.6%	.6%	2.3%

Source: San Diego Air Quality Planning Report, "Transportation Management Tactics for Air Quality Improvement," April 1976.

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(8) Work and Driving Schedule Shifts

Changes in freeway and arterial % ADTs are as follows for 1985 and 1995:

Hour	Freeway %	Arterial %
6	7.2	5.9
7	7.2	5.9
8	7.2	5.9
15	8.4	8.2
16	8.3	8.2
17	8.3	8.1

The above percentages represent a flattening out of a.m. and p.m. peak periods to represent staggered work hours.

The following tables present breakdowns of CO and NMHC emissions under the proposed control strategies for 1980, 1985, 1990, 1995, and 2000. Also included are breakdowns of the "no control" case which actually include traffic system improvements, improved mass transit, and regional development planning. Breakdowns for clean air rebate and dealer emission guarantees are not included because no reduction over no control is forecast since these strategies are designed to support the inspection/

maintenance or periodic maintenance programs and would, by themselves, be ineffective in bringing down vehicle emissions. Breakdowns for bicycle systems are not included for 1980 and 1985 since no reduction is expected until 1990, while breakdowns for work and driving schedule shifts are presented only for 1985 and 1995 because detailed traffic data is not available for the other years of interest.

Table E-1. **EMISSIONS BREAKDOWN FOR THE BASE CASE IN 1980.**

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	293.6	59.4
b. Light Duty Gas Trucks	109.1	22.0
c. Heavy Duty Gas Trucks	132.1	15.2
d. Light Duty Diesel Vehicles	< 0.1	<0.1
e. Heavy Duty Diesel Vehicles	4.6	0.9
f. Motorcycles	4.0	0.9
TOTAL	543.4	98.4
2. Secondary Traffic	91.7	14.9
TOTAL TRAFFIC	635.1	114.3
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.8	--
b. Comm./Inst.	1.3	0.3
c. Industrial	5.8	1.7
d. Miscellaneous	1.2	50.1
5. Airports	27.9	3.0
6. Railroads	3.2	2.3
TOTAL NON-TRAFFIC	40.9	70.9
TOTAL	676.0	185.2

Table E-2. EMISSIONS BREAKDOWN FOR THE INSPECTION/MAINTENANCE CONTROL STRATEGY IN 1980.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	229.0	37.4
b. Light Duty Gas Trucks	85.1	13.9
c. Heavy Duty Gas Trucks	117.6	14.1
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	4.1	0.8
f. Motorcycles	3.1	0.6
TOTAL	438.9	66.8
2. Secondary Traffic	71.5	9.4
TOTAL TRAFFIC	510.4	76.2
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.8	--
b. Comm./Inst.	1.3	0.3
c. Industrial	5.8	1.7
d. Miscellaneous	1.2	50.1
5. Airports	27.9	3.0
6. Railroads	3.2	2.3
TOTAL NON-TRAFFIC	40.9	70.9
TOTAL	551.3	147.1

Table E-3. EMISSIONS BREAKDOWN FOR THE PERIODIC MAINTENANCE CONTROL STRATEGY IN 1980.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	190.8	39.2
b. Light Duty Gas Trucks	70.9	14.5
c. Heavy Duty Gas Trucks	85.9	10.0
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	3.0	0.6
f. Motorcycles	2.6	0.6
TOTAL	353.2	64.9
2. Secondary Traffic	59.6	9.8
TOTAL TRAFFIC	412.8	74.7
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.8	--
b. Comm./Inst.	1.3	0.3
c. Industrial	5.8	1.7
d. Miscellaneous	1.2	50.1
5. Airports	27.9	3.0
6. Railroads	3.2	2.3
TOTAL NON-TRAFFIC	40.9	70.9
TOTAL	453.7	145.6

Table E-4. EMISSIONS BREAKDOWN FOR THE VAPOR RECOVERY CONTROL STRATEGY IN 1980.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	293.6	59.4
b. Light Duty Gas Trucks	109.1	22.0
c. Heavy Duty Gas Trucks	132.1	15.2
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	4.6	0.9
f. Motorcycles	4.0	0.9
TOTAL	543.4	98.4
2. Secondary Traffic	91.7	14.9
TOTAL TRAFFIC	635.1	114.3
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.8	--
b. Comm./Inst.	1.3	0.3
c. Industrial	5.8	1.7
d. Miscellaneous	1.2	46.0
5. Airports	27.9	3.0
6. Railroads	3.2	2.3
TOTAL NON-TRAFFIC	40.9	66.8
TOTAL	676.0	181.1

Table E-5. EMISSIONS BREAKDOWN FOR THE CARPOOLING STRATEGY IN 1980.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	284.8	57.6
b. Light Duty Gas Trucks	105.8	21.3
c. Heavy Duty Gas Trucks	132.1	15.2
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	4.6	0.9
f. Motorcycles	4.0	0.9
TOTAL	531.3	95.9
2. Secondary Traffic	88.9	14.5
TOTAL TRAFFIC	620.2	110.4
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.8	--
b. Comm./Inst.	1.3	0.3
c. Industrial	5.8	1.7
d. Miscellaneous	1.2	50.1
5. Airports	27.9	3.0
6. Railroads	3.2	2.3
TOTAL NON-TRAFFIC	40.9	70.9
TOTAL	661.1	181.3

Table E-6. EMISSIONS BREAKDOWN FOR THE BASE CASE IN 1985.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	116.3	32.8
b. Light Duty Gas Trucks	67.1	15.1
c. Heavy Duty Gas Trucks	123.7	11.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	5.3	1.1
f. Motorcycles	4.2	0.9
TOTAL	316.6	61.2
2. Secondary Traffic	47.6	9.2
TOTAL TRAFFIC	364.2	70.4
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.9	--
b. Comm./Inst.	1.5	0.4
c. Industrial	5.8	1.7
d. Miscellaneous	1.4	47.6
5. Airports	28.7	3.1
6. Railroads	3.4	2.4
TOTAL NON-TRAFFIC	42.3	68.7
TOTAL	406.5	139.1

Table E-7. EMISSIONS BREAKDOWN FOR THE INSPECTION/MAINTENANCE STRATEGY IN 1985.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	90.7	20.7
b. Light Duty Gas Trucks	52.3	9.5
c. Heavy Duty Gas Trucks	110.1	10.6
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	4.7	1.0
f. Motorcycles	3.2	0.6
TOTAL	261.1	42.4
2. Secondary Traffic	37.1	5.8
TOTAL TRAFFIC	298.2	48.2
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.9	--
b. Comm./Inst.	1.5	0.4
c. Industrial	5.8	1.7
d. Miscellaneous	1.4	47.6
5. Airports	28.7	3.1
6. Railroads	3.4	2.4
TOTAL NON-TRAFFIC	42.3	68.7
TOTAL	340.5	116.9

Table E-8. EMISSIONS BREAKDOWN FOR THE PERIODIC MAINTENANCE STRATEGY IN 1985.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	75.6	21.6
b. Light Duty Gas Trucks	43.6	10.0
c. Heavy Duty Gas Trucks	80.4	7.5
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	3.5	0.7
f. Motorcycles	2.7	0.6
TOTAL	205.7	40.4
2. Secondary Traffic	30.9	6.1
TOTAL TRAFFIC	236.7	46.5
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.9	--
b. Comm./Inst.	1.5	0.4
c. Industrial	5.8	1.7
d. Miscellaneous	1.4	47.6
5. Airports	28.7	3.1
6. Railroads	3.4	2.4
TOTAL NON-TRAFFIC	42.3	68.7
TOTAL	279.0	115.2

Table E-9. EMISSIONS BREAKDOWN FOR THE VAPOR RECOVERY STRATEGY IN 1985.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	116.3	32.8
b. Light Duty Gas Trucks	67.1	15.1
c. Heavy Duty Gas Trucks	123.7	11.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	5.3	1.1
f. Motorcycles	4.2	0.9
TOTAL	316.6	61.2
2. Secondary Traffic	47.6	9.2
TOTAL TRAFFIC	364.2	70.4
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.9	--
b. Comm./Inst.	1.5	0.4
c. Industrial	5.8	1.7
d. Miscellaneous	1.4	38.0
5. Airports	28.7	3.1
6. Railroads	3.4	2.4
TOTAL NON-TRAFFIC	42.3	59.1
TOTAL	406.5	129.5

Table E-10. EMISSIONS BREAKDOWN FOR THE CARPOOLING STRATEGY IN 1985.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	110.4	31.2
b. Light Duty Gas Trucks	63.7	14.3
c. Heavy Duty Gas Trucks	123.7	11.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	5.3	1.1
f. Motorcycles	4.2	0.9
TOTAL	307.3	58.8
2. Secondary Traffic	45.2	8.8
TOTAL TRAFFIC	352.5	67.6
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.9	--
b. Comm./Inst.	1.5	0.4
c. Industrial	5.8	1.7
d. Miscellaneous	1.4	47.6
5. Airports	28.7	3.1
6. Railroads	3.4	2.4
TOTAL NON-TRAFFIC	42.3	68.7
TOTAL	394.8	136.3

Table E-11. EMISSIONS BREAKDOWN FOR THE WORK AND DRIVING SCHEDULE SHIFTS STRATEGY IN 1985.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	116.1	32.8
b. Light Duty Gas Trucks	67.0	15.1
c. Heavy Duty Gas Trucks	123.0	11.3
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	5.3	1.0
f. Motorcycles	4.2	0.9
TOTAL	315.6	61.1
2. Secondary Traffic	47.5	9.2
TOTAL TRAFFIC	363.1	70.3
3. Point Sources	0.7	13.5
4. Area Sources		
a. Residential	0.9	--
b. Comm./Inst.	1.5	0.4
c. Industrial	5.8	1.7
d. Miscellaneous	1.4	47.6
5. Airports	28.7	3.1
6. Railroads	3.4	2.4
TOTAL NON-TRAFFIC	42.3	68.7
TOTAL	405.4	139.0

Table E-12. EMISSIONS BREAKDOWN FOR THE BASE CASE IN 1990.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	59.8	21.1
b. Light Duty Gas Trucks	50.3	11.7
c. Heavy Duty Gas Trucks	135.2	10.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	6.2	1.2
f. Motorcycles	1.4	0.4
TOTAL	252.9	44.8
2. Secondary Traffic	29.6	6.0
TOTAL TRAFFIC	282.5	50.8
3. Point Sources	0.6	13.5
4. Area Sources		
a. Residential	1.0	--
b. Comm./Inst.	1.6	0.4
c. Industrial	7.8	2.3
d. Miscellaneous	1.6	44.9
5. Airports	32.3	3.2
6. Railroads	3.8	2.7
TOTAL NON-TRAFFIC	48.7	67.0
TOTAL	331.2	117.8

Table E-13. EMISSIONS BREAKDOWN FOR THE INSPECTION/MAINTENANCE STRATEGY IN 1990.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	46.4	13.3
b. Light Duty Gas Trucks	39.2	7.4
c. Heavy Duty Gas Trucks	120.3	9.6
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	5.5	1.1
f. Motorcycles	1.1	0.3
TOTAL	212.5	31.7
2. Secondary Traffic	23.1	3.3
TOTAL TRAFFIC	235.6	35.0
3. Point Sources	0.6	13.5
4. Area Sources		
a. Residential	1.0	--
b. Comm./Inst.	1.6	0.4
c. Industrial	7.8	2.3
d. Miscellaneous	1.6	44.9
5. Airports	32.3	3.2
6. Railroads	3.8	2.7
TOTAL NON-TRAFFIC	48.7	67.0
TOTAL	284.3	102.0

Table E-14. EMISSIONS BREAKDOWN FOR THE PERIODIC MAINTENANCE STRATEGY IN 1990.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	38.9	13.9
b. Light Duty Gas Trucks	32.7	7.7
c. Heavy Duty Gas Trucks	87.9	6.9
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	4.0	0.8
f. Motorcycles	0.9	0.3
TOTAL	164.4	29.6
2. Secondary Traffic	19.2	4.0
TOTAL TRAFFIC	183.6	33.6
3. Point Sources	0.6	13.5
4. Area Sources		
a. Residential	1.0	--
b. Comm./Inst.	1.6	0.4
c. Industrial	7.8	2.3
d. Miscellaneous	1.6	44.9
5. Airports	32.3	3.2
6. Railroads	3.8	2.7
TOTAL NON-TRAFFIC	48.7	67.0
TOTAL	232.3	100.6

Table E-15. EMISSIONS BREAKDOWN FOR THE VAPOR RECOVERY STRATEGY IN 1990.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	59.8	21.1
b. Light Duty Gas Trucks	50.3	11.7
c. Heavy Duty Gas Trucks	135.2	10.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	6.2	1.2
f. Motorcycles	1.4	0.4
TOTAL	252.9	44.8
2. Secondary Traffic	29.6	6.0
TOTAL TRAFFIC	282.5	50.8
3. Point Sources	0.6	13.5
4. Area Sources		
a. Residential	1.0	--
b. Comm./Inst.	1.6	0.4
c. Industrial	7.8	2.3
d. Miscellaneous	1.6	27.1
5. Airports	32.3	3.2
6. Railroads	3.8	2.7
TOTAL NON-TRAFFIC	48.7	49.2
TOTAL	331.2	100.0

Table E-16. EMISSIONS BREAKDOWN FOR THE CARPOOLING STRATEGY IN 1990.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	54.7	19.4
b. Light Duty Gas Trucks	46.0	10.8
c. Heavy Duty Gas Trucks	135.2	10.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	6.2	1.2
f. Motorcycles	1.4	.4
TOTAL	243.5	42.2
2. Secondary Traffic	27.1	5.5
TOTAL TRAFFIC	270.6	47.7
3. Point Sources	0.6	13.5
4. Area Sources		
a. Residential	1.0	--
b. Comm./Inst.	1.6	0.4
c. Industrial	7.8	2.3
d. Miscellaneous	1.6	44.9
5. Airports	32.3	3.2
6. Railroads	3.8	2.7
TOTAL NON-TRAFFIC	48.7	67.0
TOTAL	318.3	114.7

Table E-17. EMISSIONS BREAKDOWN FOR THE BICYCLE SYSTEM STRATEGY IN 1990.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	59.4	21.0
b. Light Duty Gas Trucks	50.0	11.6
c. Heavy Duty Gas Trucks	135.2	10.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	6.2	1.2
f. Motorcycles	1.4	.4
TOTAL	252.3	44.6
2. Secondary Traffic	29.4	6.0
TOTAL TRAFFIC	281.7	50.6
3. Point Sources	0.6	13.5
4. Area Sources		
a. Residential	1.0	--
b. Comm./Inst.	1.6	0.4
c. Industrial	7.8	2.3
d. Miscellaneous	1.6	44.9
5. Airports	32.3	3.2
6. Railroads	3.8	2.7
TOTAL NON-TRAFFIC	48.7	67.0
TOTAL	330.4	117.6

Table E-18. EMISSIONS BREAKDOWN FOR THE BASE CASE IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	65.4	21.9
b. Light Duty Gas Trucks	57.2	11.1
c. Heavy Duty Gas Trucks	155.4	12.7
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	7.2	1.5
f. Motorcycles	1.6	0.5
TOTAL	286.9	47.7
2. Secondary Traffic	31.7	6.5
TOTAL TRAFFIC	318.6	54.1
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	39.8
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	62.9
TOTAL	374.2	117.0

Table E-19. EMISSIONS BREAKDOWN FOR THE INSPECTION/MAINTENANCE STRATEGY IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	51.0	13.8
b. Light Duty Gas Trucks	44.6	7.0
c. Heavy Duty Gas Trucks	138.3	11.8
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	6.4	1.4
f. Motorcycles	1.3	0.3
TOTAL	241.6	34.3
2. Secondary Traffic	24.8	4.1
TOTAL TRAFFIC	266.4	38.4
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	39.8
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	62.9
TOTAL	322.0	101.3

Table E-20. EMISSIONS BREAKDOWN FOR THE PERIODIC MAINTENANCE STRATEGY IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	42.5	14.4
b. Light Duty Gas Trucks	37.2	7.3
c. Heavy Duty Gas Trucks	101.0	8.4
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	4.7	1.0
f. Motorcycles	1.1	0.3
TOTAL	186.5	31.4
2. Secondary Traffic	20.6	4.3
TOTAL TRAFFIC	207.1	35.7
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	39.8
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	62.9
TOTAL	262.7	98.6

Table E-21. EMISSIONS BREAKDOWN FOR THE VAPOR RECOVERY STRATEGY IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	65.4	21.9
b. Light Duty Gas Trucks	57.2	11.1
c. Heavy Duty Gas Trucks	155.4	12.7
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	7.2	1.5
f. Motorcycles	1.6	0.5
TOTAL	286.9	47.7
2. Secondary Traffic	31.7	6.0
TOTAL TRAFFIC	318.6	53.7
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	12.0
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	35.1
TOTAL	374.2	88.8

Table E-22. EMISSIONS BREAKDOWN FOR THE CARPOOLING STRATEGY IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	57.5	19.5
b. Light Duty Gas Trucks	50.4	9.9
c. Heavy Duty Gas Trucks	155.4	12.7
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	7.2	1.5
f. Motorcycles	1.6	0.5
TOTAL	272.1	44.1
2. Secondary Traffic	27.9	5.8
TOTAL TRAFFIC	300.0	49.9
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	39.8
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	62.9
TOTAL	355.6	112.8

Table E-23. EMISSIONS BREAKDOWN FOR THE BICYCLE SYSTEM STRATEGY IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	65.0	21.7
b. Light Duty Gas Trucks	56.9	11.1
c. Heavy Duty Gas Trucks	155.4	12.7
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	7.2	1.5
f. Motorcycles	1.6	0.4
TOTAL	286.1	47.4
2. Secondary Traffic	31.5	6.4
TOTAL TRAFFIC	317.6	53.8
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	39.8
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	62.9
TOTAL	373.2	116.7

Table E-24. EMISSIONS BREAKDOWN FOR THE WORK AND DRIVING SHIFT STRATEGY IN 1995.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	65.2	21.9
b. Light Duty Gas Trucks	57.1	11.1
c. Heavy Duty Gas Trucks	154.5	12.7
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	7.1	1.5
f. Motorcycles	1.6	0.5
TOTAL	285.5	47.7
2. Secondary Traffic	31.7	6.5
TOTAL TRAFFIC	317.2	54.1
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.1	--
b. Comm./Inst.	1.7	0.4
c. Industrial	10.1	2.9
d. Miscellaneous	1.8	39.8
5. Airports	36.1	3.4
6. Railroads	4.2	3.0
TOTAL NON-TRAFFIC	55.6	62.9
TOTAL	372.8	117.0

Table E-25. EMISSIONS BREAKDOWN FOR THE BASE CASE IN 2000.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	74.4	24.6
b. Light Duty Gas Trucks	65.6	12.7
c. Heavy Duty Gas Trucks	177.9	14.5
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	8.1	1.7
f. Motorcycles	1.8	.5
TOTAL	327.8	54.0
2. Secondary Traffic	38.9	7.0
TOTAL TRAFFIC	366.7	61.0
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.2	--
b. Comm./Inst.	1.9	0.5
c. Industrial	13.5	3.9
d. Miscellaneous	2.0	44.3
5. Airports	39.7	3.5
6. Railroads	4.6	3.3
TOTAL NON-TRAFFIC	63.5	68.9
TOTAL	430.2	129.9

Table E-26. EMISSIONS BREAKDOWN FOR THE INSPECTION/MAINTENANCE STRATEGY IN 2000.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	58.0	15.5
b. Light Duty Gas Trucks	51.1	8.0
c. Heavy Duty Gas Trucks	158.3	13.5
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	7.0	1.6
f. Motorcycles	1.4	0.3
TOTAL	275.8	38.9
2. Secondary Traffic	30.3	4.4
TOTAL TRAFFIC	306.1	43.3
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.2	--
b. Comm./Inst.	1.9	0.5
c. Industrial	13.5	3.9
d. Miscellaneous	2.0	44.3
5. Airports	39.7	3.5
6. Railroads	4.6	3.3
TOTAL NON-TRAFFIC	63.5	68.9
TOTAL	369.6	112.2

Table E-27. EMISSIONS BREAKDOWN FOR THE PERIODIC MAINTENANCE STRATEGY IN 2000.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	48.4	16.2
b. Light Duty Gas Trucks	42.6	8.4
c. Heavy Duty Gas Trucks	115.6	9.6
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	5.3	1.1
f. Motorcycles	1.2	0.3
TOTAL	213.1	35.6
2. Secondary Traffic	25.3	4.6
TOTAL TRAFFIC	238.4	40.2
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.2	--
b. Comm./Inst.	1.9	0.5
c. Industrial	13.5	3.9
d. Miscellaneous	2.0	44.3
5. Airports	39.7	3.5
6. Railroads	4.6	3.3
TOTAL NON-TRAFFIC	63.5	68.9
TOTAL	302.9	109.1

Table E-28. EMISSIONS BREAKDOWN FOR THE VAPOR RECOVERY STRATEGY IN 2000.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	74.4	24.6
b. Light Duty Gas Trucks	65.6	12.7
c. Heavy Duty Gas Trucks	177.9	14.5
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	8.1	1.7
f. Motorcycles	1.8	.5
TOTAL	327.8	54.0
2. Secondary Traffic	38.9	7.0
TOTAL TRAFFIC	366.7	61.0
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.2	--
b. Comm./Inst.	1.9	0.5
c. Industrial	13.5	3.9
d. Miscellaneous	2.0	13.3
5. Airports	39.7	3.5
6. Railroads	[illegible].6	3.3
TOTAL NON-TRAFFIC	63.5	37.9
TOTAL	430.2	98.9

Table E-29. EMISSIONS BREAKDOWN FOR THE CARPOOLING STRATEGY IN 2000.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	62.9	21.2
b. Light Duty Gas Trucks	55.4	10.9
c. Heavy Duty Gas Trucks	177.9	14.5
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	8.1	1.7
f. Motorcycles	1.8	0.5
TOTAL	304.3	48.8
2. Secondary Traffic	32.9	6.0
TOTAL TRAFFIC	337.2	54.8
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.2	--
b. Comm./Inst.	1.9	0.5
c. Industrial	13.5	3.9
d. Miscellaneous	2.0	44.3
5. Airports	39.7	3.5
6. Railroads	4.6	3.3
TOTAL NON-TRAFFIC	63.5	68.9
TOTAL	400.7	123.7

Table E-30. EMISSIONS BREAKDOWN FOR THE BICYCLE SYSTEM STRATEGY IN 2000.

Category	CO tons/day	NMHC tons/day
1. Primary Traffic		
a. Light Duty Gas Vehicles	74.0	24.5
b. Light Duty Gas Trucks	65.2	12.6
c. Heavy Duty Gas Trucks	177.9	14.5
d. Light Duty Diesel Vehicles	< 0.1	< 0.1
e. Heavy Duty Diesel Vehicles	8.1	1.7
f. Motorcycles	1.8	0.5
TOTAL	327.0	53.8
2. Secondary Traffic	38.7	7.0
TOTAL TRAFFIC	365.7	60.8
3. Point Sources	0.6	13.4
4. Area Sources		
a. Residential	1.2	--
b. Comm./Inst.	1.9	0.5
c. Industrial	13.5	3.9
d. Miscellaneous	2.0	44.3
5. Airports	39.7	3.5
6. Railroads	4.6	3.3
TOTAL NON-TRAFFIC	63.5	68.9
TOTAL	429.2	129.7

APPENDIX F

Description of the APRAC-II Model

APRAC-1A is a diffusion model developed by Ludwig, et al (1970) for computing the concentrations of inert, vehicle-generated pollutants at any point within a city. The acronym APRAC stands for Air Pollution Research Advisory Committee, under whose auspices the development of the model was conducted. The members of this committee were drawn from the Coordinating Research Council and the Environmental Protection Agency.

This model is basically a modified version of the receptor-oriented Gaussian plume formulation developed by Clarke (1964). The source code is contained in the User's Network for Applied Modeling of Air Pollution (UNAMAP) available on magnetic tape through the National Technical Information Service. The program is written in FORTRAN IV for an IBM 360/50 computer but is easily adapted to other systems with a FORTRAN IV compiler. Instructions in running the program can be found in the User's Manual for the APRAC-1A Urban Diffusion Model Computer Program (Mancuso, et al, 1972).

Three different types of analyses can be performed using this model: synoptic, climatological, and grid point. There is also a street canyon option for synoptic and climatological models. The synoptic model gives temporal variations of hourly pollution concentrations at up to ten receptor points. The climatological model gives concentration frequency distributions at one receptor based on historical meteorological and traffic input data. The grid point model gives an average concentration at particular hour at up to 625 receptor points.

F.1 The Basic Model

The model uses a combination of the "Gaussian plume" and "box" model diffusion formulations. Basically, the Gaussian plume model assumes that the vertical concentration profile from a crosswind line source is Gaussian in shape as shown in Figure F-1. The spread of this vertical concentration distribution is described by the standard deviation, σ_z, taken to have the form

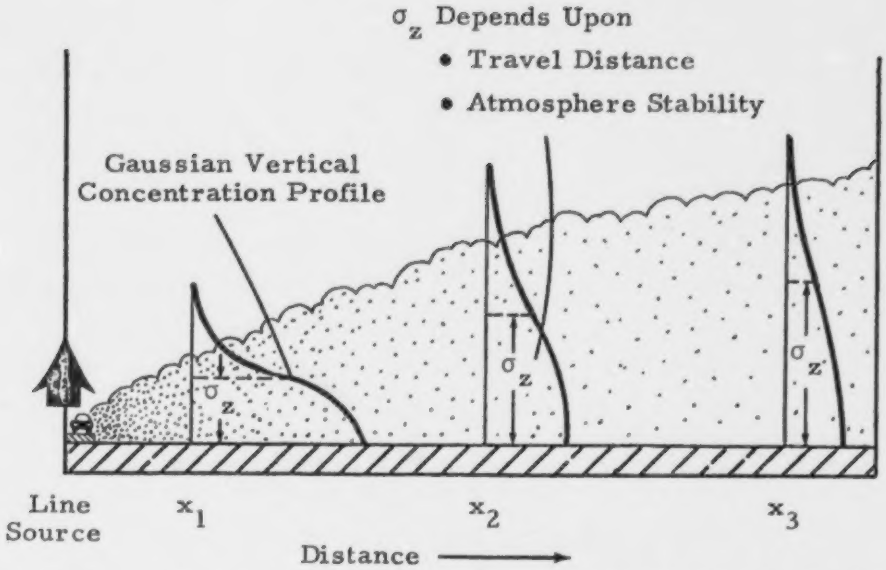
σ_z Depends Upon
• Travel Distance
• Atmosphere Stability
Gaussian Vertical Concentration Profile
σ_z
σ_z
σ_z
Line Source
x_1
x_2
x_3
Distance ⟶

Figure F-1. Vertical Diffusion According to Gaussian Formulation.

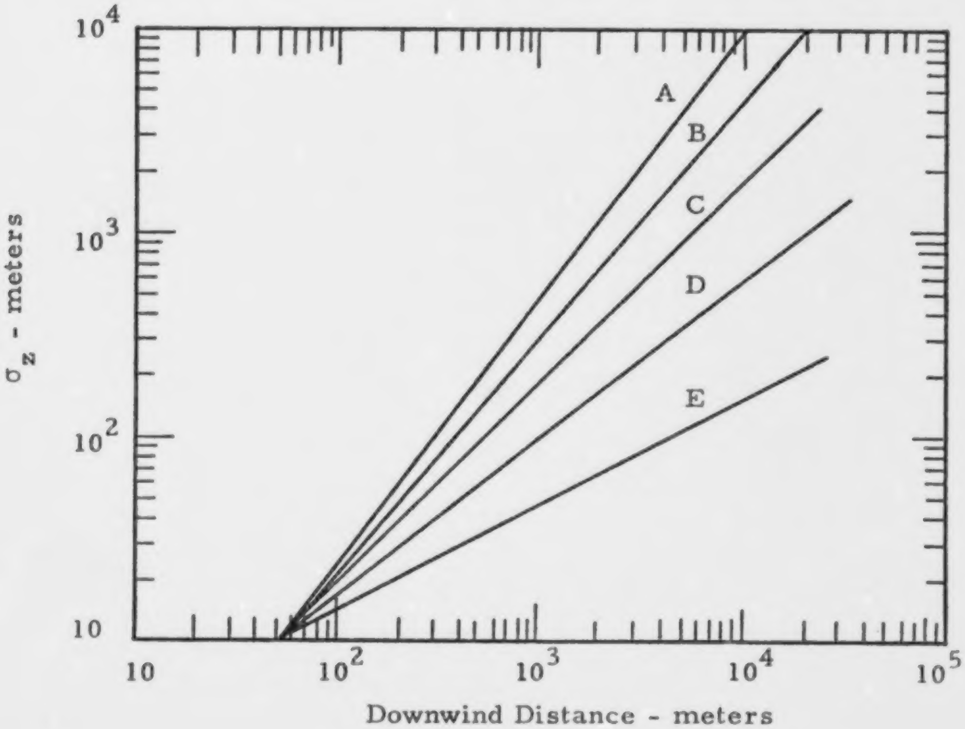

Figure F-2. Vertical Diffusion As a Function of Travel Distance and Stability Category, As Revised For Urban Conditions.

$$\sigma_z = ax^b \ldots . \qquad \text{(F-1)}$$

where x is the downwind distance and the parameters a and b depend upon atmospheric stability. The curves in Figure F-2 represent conditions from extremely unstable (A) to moderately stable (E).

When vertical mixing is inhibited, the box model is applied to emissions from sources relatively distant from the receptor. The receptor is the point for which the concentrations are being calculated. Emissions tend to become uniformly distributed in the vertical up to the limiting mixing height after sufficient travel has taken place.

The models are applied to ten area sources, each of which is assumed to have source emissions spread uniformly throughout. These area sources are oriented in the upwind direction as shown in Figure F-3. The outer sectors have an angular width of 22.5°, corresponding to the plume width ($\pm 2\sigma$) predicted by Gifford (1961) for slightly unstable conditions. The inner sectors have an angular width of 45°. These broader sectors allow for larger initial dispersion, as observed by Pooler (1966) and McElroy (1969). The logarithmic spacing of the area boundaries allows the nearby sources to be considered in greater detail than the farther sources, whose individual contributions tend to be merged during their longer travel.

The contributions of each of the ten area sources to the CO concentration at the receptor are computed individually with one of the simple formulations given below. For the closer segments the Gaussian formulation is used to obtain the concentration C_i resulting from emissions in the i^{th} segment:

$$C_i = \frac{0.8\, Q_{Ai}}{u\, a_j} \left(1 - b_j\right)^{-1} \left(x_{i+1}^{\,1-b_j} - x_i^{\,1-b_j}\right) , \qquad \text{(F-2)}$$

where Q_{Ai} is the average area emission rate(gm $m^{-2}s^{-1}$) u is the transport wind speed (ms^{-1}), and a_j and b_j are the constants appropriate to the

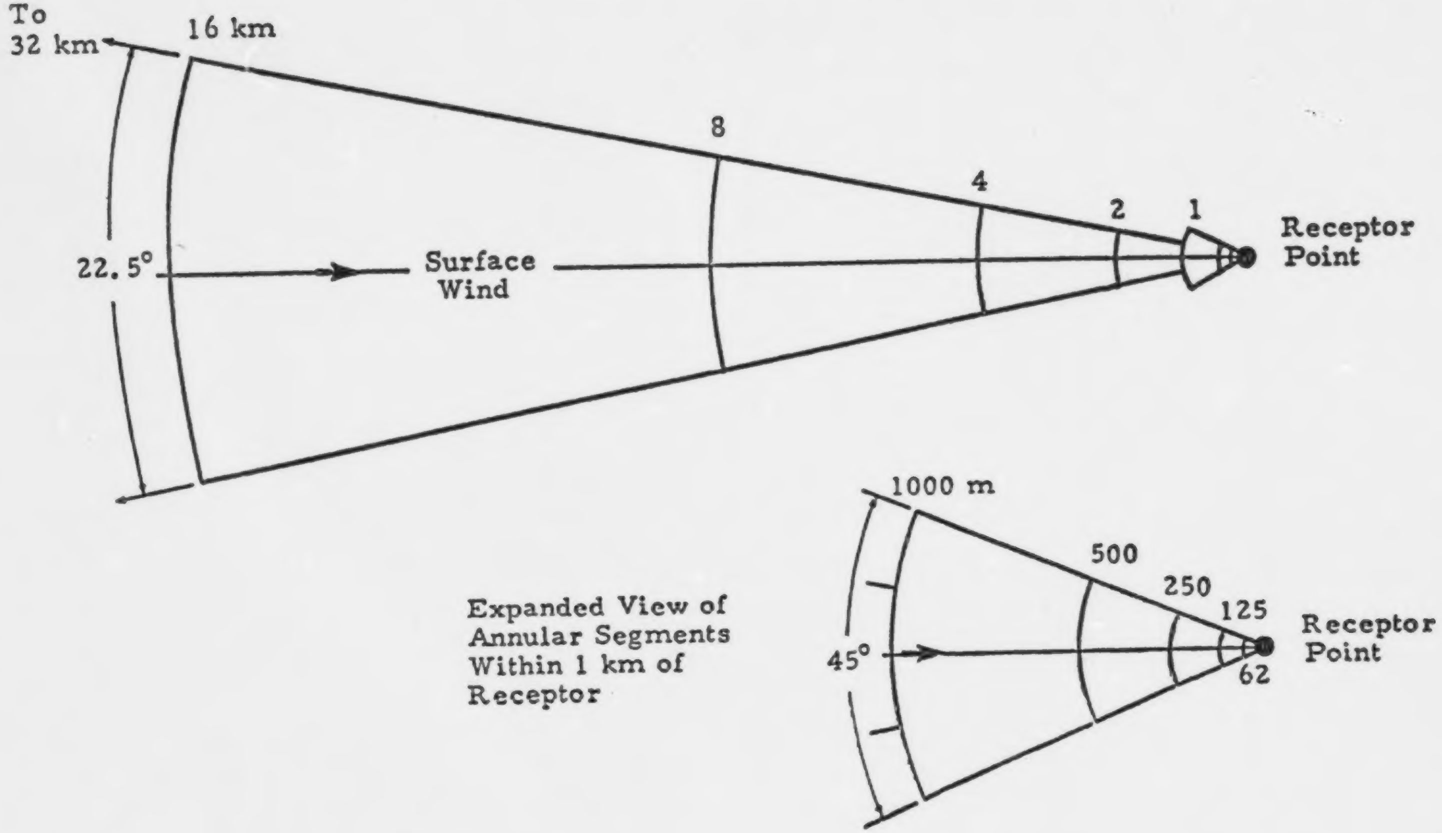
To
32 km
16 km
8
4
2
1
Receptor
Point
22.5°
Surface
Wind
1000 m
500
250
125
62
Receptor
Point
45°
Expanded View of
Annular Segments
Within 1 km of
Receptor

FIGURE F-3. Diagram of segments used for spatial partitioning of emissions.

segment and atmospheric stability class j. The x's are the distances to the closest boundary of the segment designated by the subscript, i.

The model changes from the Gaussian formulation to the box model as a distance where the two (in their respective line source formulations) give equal surface concentration values. The box model concentration is given by the following equation:

$$C_i = Q_{Ai} \frac{x_{i+1} - x_i}{u\,h} , \qquad \text{(F-3)}$$

where h is the mixing height. The contributions of the emissions in each segment, as determined from Eqns. F-2 and F-3 are summed to obtain the concentration at the receptor.

In order to apply Eqns. F-2 and F-3, the model requires the following input variables:

1. traffic emissions
2. mixing height
3. atmospheric stability type
4. transport wind speed and direction

o Traffic Emissions

Emissions are computed in the model using a traffic inventory consisting of a network of traffic road segments or links. Each link is assigned an average daily traffic volume, based upon historical or forecast data. It is identified in the computer memory by its length and the geographical locations of its end points and is classified by roadway type on the basis of vehicular speed. To take into account diurnal variations, daily traffic volumes are multiplied by an adjustment factor to obtain traffic volume for a particular hour.

The CO emission rate, E, (gm/vehicle-miles) is obtained from the mean vehicular speed, S (mph), by an empirical equation of the form

$$E = \alpha S^{-\beta} \ldots . \qquad \text{(F-4)}$$

where α and β are constants that depend on emissions control characteristics and vehicular model mix. For cars produced since 1968, β has been 0.48. Existing and potential legislation requires α to decrease with time (Table F-1). For future years, the effective value of α and β have to be determined on the basis of the fraction of the total cars represented by each model year (Johnson, et al, 1971; Dabberdt, et al, 1973; Ludwig, et al, 1972).

TABLE F-1. Values of α for cars produced after 1970.

Model Years	α
1972-1974	160
1975-1979	16
After 1980	8

The total hourly CO emission for a given traffic link is the product of three factors: the emission rate, the length of the link, and the hourly traffic volume. For a given sector (Figure F-3) the emissions from all the links or parts of links that fall within that sector were aggregated to determine the average emissions.

- Mixing Height

The determination of mixing height was based on the assumption that for an atmosphere which started out with a low-lying inversion early in the morning, convection will be caused by ground heating and that the entire convective (mixed) layer is adiabatically adjusted so that the erosion on the inversion base will be a direct response to this adjustment. Thus, by using the observed morning lapse rate and the surface temperature at a given hour during the day, it was possible to determine the height of the mixing layer by the intersection of the morning sounding and a dry adiabat. This method is fairly common (Holzworth, 1967) for meteorological application.

During the daylight hours, the surface temperatures at the airport observation site are used. During the predawn hours, and for those cases which showed a ground-based inversion, the mixing height over the city was based on the urban heat island models of Summers (1966) and Ludwig (1968, 1970). These models developed empirical relationships between rural lapse rates and the intensity of urban heat islands. After sunset the model interpolates between the afternoon mixing depth and that for the predawn hours of the following morning.

- Atmospheric Stability

Plume spread is a function of turbulence. This latter may be parameterized in terms of atmospheric stability. Following the works of Pasquill (1961) and Turner (1964), atmospheric conditions are classified according to prevailing insolation strength and wind speed for daytime conditions, and according to cloud cover and wind speed for nighttime conditions (Table F-2).

Insolation strength is computed using the equation

$$\text{Insolation strength} = k\,(1 - AN)\sin\theta$$

where k = a proportionality factor, depending on the solar constant, and atmospheric transmission

A = the average albedo or reflectance of the clouds

N = the fraction of the sky obscured by cloud

θ = the elevation angle of the sun

TABLE F-2. Stability categories.*

Surface Winds (Knots)	Daytime Insolation			Night Clouds	
	Strong	Moderate	Slight	≥5/10	≤4/10
≤ 3	1	2	2	5	5
3-6	1	2	3	4	5
6-10	2	3	3	4	4
10-12	3	3	4	4	4
≥ 13	3	4	4	4	4

*1 = extremely unstable
2 = moderately unstable
3 = slightly unstable
4 = neutral
5 = slightly stable

Insolation is slight when $0 < (1 - 0.5\ N) \sin\theta \leq 0.33$; moderate when $0.33 < (1 - 0.5\ N) \sin\theta \leq 0.67$, and strong when $(1 - 0.5\ N) \sin\theta > 0.67$.

- Wind Speed and Direction

The model assumes a uniform wind field over the entire study area. This assumption is dictated by the fact that many cities have only one weather observation station. This is not too serious when the study area has relatively simple geography. However, the assumption becomes invalid when the study area is dominated by local circulations, e.g., valley and mountain winds, land and sea breezes, etc.

F.2 APRAC Model as Modified by AeroVironment - APRAC-II

The original version of the APRAC-1A model developed by SRI in 1972 has some obvious drawbacks.

Improvements of the model are presented below.

- Wind

The assumption of a uniform wind direction and speed for an entire study region is one of the drawbacks. There is no *a priori* reason why wind should be uniform over a city. In APRAC-II, a subroutine called WIND, developed by SRI under an ongoing contract with EPA Region IX, is used to interpolate wind at a given receptor.

In subroutine WIND, if only one wind, usually the airport observation, is provided, then that value is used for every receptor location. If wind observations are available from more than one location, this subroutine uses all observations within ten kilometers of the receptor for the interpolation. If no wind observations are available within ten kilometers, then the interpolation will be based on those data from those wind stations within 20 kilometers. If no observations are available within this larger radius, then the airport wind (or whatever wind is first on the input list) is used.

The interpolation scheme uses weighted averages of the wind components. The weighting factors are inversely proportional to the square of the distance between the receptor and the wind site. More weight is given to wind observations when they are made directly upwind or downwind of the receptor than when they are removed to one side. This feature is included to reflect the tendency of winds to change more rapidly in cross-streamline directions than along the streamlines.

The interpolation scheme used in this routine was derived from that used by Heffter and Taylor (1975). The vector averaged wind is given by

$$\vec{V} = \frac{\overset{R}{\Sigma} D_i A_i \vec{W}_i}{\overset{R}{\Sigma} D_i A_i}$$

where $\vec{V}$ = interpolated wind vector at the receptor

D_i = distance weighting factor for the i^{th} wind observation

As noted earlier, the summation radius, R, is taken as 10 km unless there are no wind observations within that distance. If there are none, R is increased to 20 km. Figure F-4 illustrates the parameters used in the wind interpolation scheme.

- o Mixing Height

In the original version of APRAC-1A, mixing heights were computed in the model from a morning temperature sounding and surface temperatures during the day and from an empirical equation derived from Summer's (1966) and Ludwig's works (1968, 1970) during the night. The modified model has the capability of accepting precomputed mixing height for the hour being modeled.

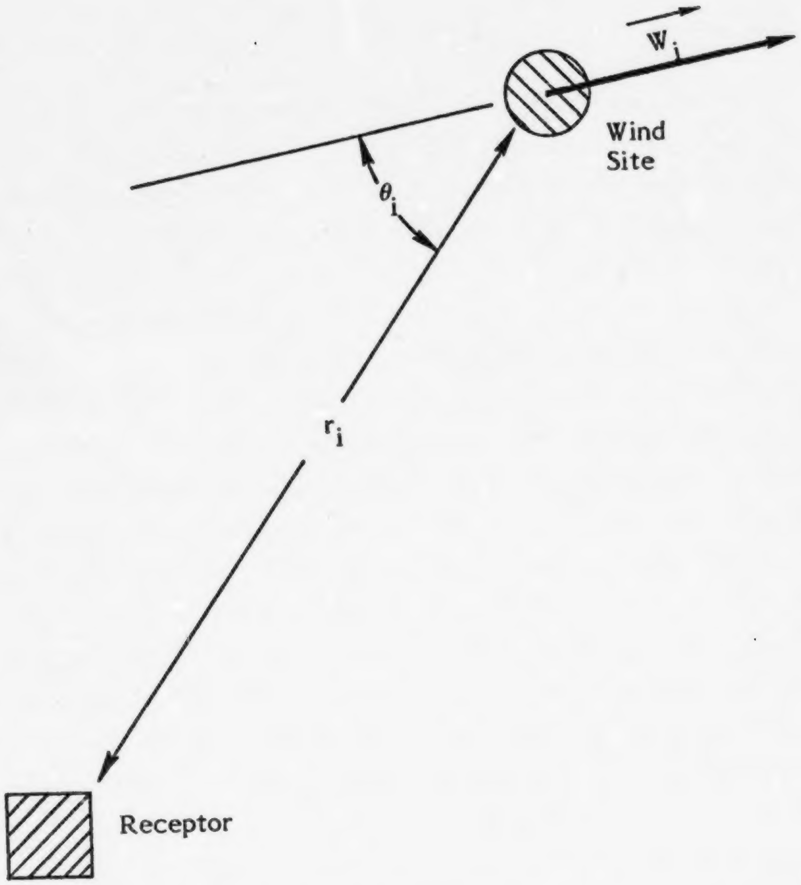
$\vec{W}_i$
Wind Site
θ_i
r_i
Receptor

FIGURE F-4. Parameters used in wind interpolation scheme.

o **Emissions**

The model now accepts non-traffic and secondary traffic emissions and assigns them into 1 mile by 1 mile grids. It also allows the input of an indefinite number of roadway links in the primary network whereas the original version limits the number of primary links to 1200.

Of all the drawbacks of the original APRAC-1A, the most serious one has to do with the computation of traffic emissions. Since CO concentrations at a receptor depend a great deal on the emissions upwind, an inaccurate specification of these emissions would unavoidably result in errors in the model output. Emissions factors in the original APRAC-1A are computed for the formula $E = \alpha S^{-\beta}$ where E is the emission factor, S is the mean vehicle speed, and α and β are constants that depend on the characteristics of the emission control devices and the mixture of old and new model cars on the road. The computations of emission factors have been greatly improved since the development of the APRAC-1A model. The latest EPA approved procedure is now published in Supplement 5 of AP-42. Instead of calculating emissions, the model now accepts emissions precomputed for each primary link and for each hour of the day. Thus, future changes in emission factors will no longer require modifying the model.

o **Line Source Model**

An additional feature of the modified model which the original one does not have is the capability of more detailed analysis of the effect of individual network links on specific receptor locations. The subroutine, LINE, used in this computation, and the series of routines called by LINE are an adaptation of the line source treatment used in SRI's ISMAP dispersion model.

The traffic link is represented by a series of point sources whose total emissions equal the link's total emissions. A distance between points that will accurately represent the line source must be chosen. The maximum tolerable error resulting from the finite distance between point sources was taken to be 5 percent. Thus,

$$\frac{\chi_{ref} - \chi}{\chi_{ref}} = 0.05 \qquad \text{(F-5)}$$

where χ_{ref} is the concentration at a receptor resulting from some reference point on the link, and χ is the concentration from a point on the link a distance ΔL away. The case in which the wind is perpendicular to the link is the most sensitive to the spacing between point sources (ΔL). Assuming the reference point to be on the centerline of the plume with the wind perpendicular to the link, Eqn. F-5 can be solved for ΔL:

$$\Delta L = \sqrt{-2n\,(0.95)\,\sigma_y^{\,2}} \qquad \text{(F-6)}$$

The distance along the wind direction used for calculation of σ_y in Eqn. F-6 is the distance from the receptor to the nearest point on each link. To be conservative, the routine uses one-half of the value of ΔL as the spacing.

Having found the spacing between point sources for the link, the subroutine proceeds to calculate the CO concentration at the receptor for each point source. The equation for the concentration from a point source is

$$\chi_p = \frac{Q_p}{\pi\,\sigma_y(d_w)\,\sigma_z(d_w)\,u}\;\exp\left\{-1/2\,\frac{d_c^{\,2}}{\sigma_y^{\,2}(d_w)}\right\}\exp\left\{-1/2\,\frac{H^2}{\sigma_z^{\,2}(d_w)}\right\} \qquad \text{(F-7)}$$

and

$$\begin{aligned} \sigma_y\,(d_w) &= a\left|d_w\right|^{b} + c \\ \sigma_z\,(d_w) &= f\left|d_w\right|^{g} + h \end{aligned} \qquad \text{(F-8)}$$

where χ_p is the CO concentration, gm m^{-3}

u is the wind speed, m sec^{-1}

Q_p is the point-source emission rate, gm sec^{-1}

$\sigma_y (d_w)$ is the lateral standard deviation of plume concentration, m

$\sigma_z (d_w)$ is the vertical standard deviation of plume concentration, m

H is the emission height, m

d_c is the crosswind distance from point source to receptor, m

d_w is the distance along wind direction from point source to receptor, m

a,b,f,g are the diffusion coefficients and exponents

c,h are the constants representing initial diffusion, m

The concentrations resulting from point sources on a link are summed for each receptor and multiplied by the distance between point sources.

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APPENDIX G

Major Assumptions of the Air Quality Maintenance Analysis

In order to facilitate updating of maintenance planning in the future, the major assumptions made in the air quality maintenance analysis are presented here.

I. CARBON MONOXIDE STANDARD ATTAINMENT

The predicted year of attainment of the carbon monoxide standard under various control strategies involves assumptions concerning meteorology, emissions, and control strategy effectiveness. All of these assumptions influence APRAC-II output. APRAC-II was used to directly forecast peak 8-hour CO readings for the base case, the work and driving schedule shift control strategy, and the combined strategies of inspection/maintenance and carpooling. Results of these APRAC-II runs were used to forecast peak 8-hour CO readings under other strategies using ratios of peak CO readings to CO emissions.

Meteorological assumptions involved the selection of the "severe-case" regime. This regime was selected on the basis of "severe" 8-hour CO readings at the monitoring sites. The second highest recorded 8-hour CO reading was used to determine this severe case, since the first highest reading was influenced by extensive controlled forest burning and, thus, it was not possible to ascertain how conducive to high CO levels meteorological conditions during that period would be. The meteorological parameters used as input into APRAC-II (i.e., wind speed and direction, surface temperature, cloud cover) were taken directly from the monitoring sites except for the case of calm winds. APRAC-II would not accept calm winds. In this case, wind speeds were set at 1 m/s with a direction agreeing with the general wind flow.

Assumptions made concerning base year and projected emissions are presented in Appendices A through E. In summary, traffic link data was supplied by Maricopa Association of Governments. Emission factors presented in Supplement 5 to AP-42 (EPA, 1976) were applied using AVSUP5, a computer program. Traffic emissions for 1980, 1990, and 2000 were interpolated or extrapolated as explained in Appendix B. Non-traffic emissions for the base year were obtained from "Emission Inventory Report for the Phoenix Study Area" (PES, 1976). Projections were made on the basis of growth and emission factor adjustments as described in Appendix D.

Control strategy effectiveness data as it relates to emission reduction is presented in Appendix E. This effectiveness data was provided by the AQMA Technical Operations Committee.

Year of attainment was obtained by plotting peak 8-hour CO concentration versus year for each strategy. The first complete year that the peak 8-hour CO reading is predicted to remain below 9.0 ppm is considered to be the year of attainment.

II. OXIDANT STANDARD ATTAINMENT

The predicted year of attainment of the oxidant standard under various control strategies involves assumptions similar to those concerning carbon monoxide, although no meteorological assumptions are necessary other than that implicit in the Appendix J method (40CFR51): climatology is assumed constant from year to year.

The Appendix J method involves forecasting the reduction of hydrocarbon emissions required to achieve the oxidant standard from the second highest 1-hour oxidant concentration. Since 1975 was selected as base year, the second high reading was 259 $\mu g/m^3$.

Control strategy effectiveness data was again provided by the AQMA Technical Operations Committee and is presented in Appendix E.

Year of attainment was obtained by plotting NMHC emissions versus year for each control strategy. The first complete year in which the NMHC emissions are predicted to remain below the maximum allowable emissions is considered to be the year of attainment.

Implicit in emission computations and projections were the following population levels: 1.23 million for 1975, 1.5 million for 1980, 1.7 million for 1985, 2.0 million for 1990, 2.2 million for 1995, and 2.5 million for 2000.

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APPENDIX H

Glossary

GLOSSARY

Ambient Air: Any unconfined portion of the atmosphere; the outside air.

Ambient Air Quality Standards: The level of air quality necessary to protect the public health or welfare from any known or anticipated adverse effects of a pollutant, as determined by the U.S. EPA.

AQMA: Air Quality Maintenance Area.

AQMATF: Air Quality Maintenance Area Task Force.

AV: AeroVironment Inc.

CO: Carbon Monoxide.

Cold operation: Representative of vehicle start-up after a long engine-off period.

Colorimetric detection: An analysis method whereby the amount of a pollutant is determined by the color change in a reagent through which a gas containing the pollutant is bubbled.

EPA: Environmental Protection Agency.

Flame ionization gas chromatography: An analysis method whereby a gas sample is passed through a column containing packing material which allows each component to pass through at a different rate. The amount of certain components (e.g. CH_4) is then determined by detecting the amount of increase in ion intensity resulting from the introduction into a hydrogen flame of the sample air.

Hot start-up condition: Representative of vehicle start-up after a short engine-off period.

Inert pollutants: Those gaseous pollutants (e.g., CO) that are relatively nonreactive (inert) with other gaseous or particulate species in the atmosphere.

Inversion: A layer of air in which temperature increases with height; a departure from the normal meteorological situation in which temperature decreases upwards from the ground. Such layers generally trap air pollutants by suppressing any upward mixing.

MAG:Maricopa Association of Governments.

mg/m^3: Milligrams per cubic meter; weight of a pollutant per cubic meter of air.

Mixing height: The height of the top of the mixing layer.

Mixing layer: That atmospheric layer through which pollutants are presumed to mix by virtue of air mass movement (convection) caused by daytime heating at the surface.

Model: A mathematical representation of the atmosphere or of particular atmospheric processes.

NDIR spectroscopy: An analysis method whereby the amount of infrared radiation absorbed in a particular wavelength determines the concentration of a gaseous component (pollutant).

NEDS: National Emissions Data System.

Neutral buffered potassium iodide colorimetric analysis: A colorimetric detection method for oxidant using neutral buffered potassium iodide as the reagent.

NMHC: Non-methane hydrocarbon.

Oxidant: Any oxygen containing substance that reacts chemically in the air to produce new substances. Oxidants are the primary contributors to photochemical smog.

PES: Pacific Environmental Services.

Photochemical pollutants: Those gaseous pollutants (e.g., ozone) that are products of photochemical reactions in the atmosphere.

ppm: Volumetric ratio of pollutant concentrations to ambient air concentrations. (parts of pollutants per million parts of air).

Precursors (of ozone): Pollutants (generally NMHC and oxides of nitrogen) which, under the influence of ultraviolet radiation, react to form ozone.

Severe case: That combination of winds, mixing height, and atmospheric stability which accompanies high levels of atmospheric pollutants.

Spatial distribution: Variation over the study region.

Stagnation: Persistence of a given volume of stable air over a region, permitting an abnormal buildup of pollutants from sources within the region.

Stable: A condition of the atmosphere in which vertical mixing is suppressed.

Unstable: A condition of the atmosphere which favors vertical mixing.

$\mu g/m^3$: Micrograms per cubic meter; weight of a pollutant per cubic meter of air.

UV photometry: An analysis method whereby the amount of a pollutant present is determined by the amount of ultraviolet radiation absorbed by that pollutant.

A more complete glossary may be obtained from the "Glossary of Terms Frequently Used in Air Pollution." Published by the American Meteorological Society (Pub. Gap-100, Reprinted 8/1/72). Another source is "Common Environmental Terms, A Glossary", put out by U.S.E.P.A (Revised Nov. 1974).